Scalable and Relocatable Interlocking Device

Natsuki Terada, MIRSE, Railway Technical Research Institute
Shunsuke Shiomi, MIRESE, Railway Technical Research Institute
Hiroyuki Fujita, MIRSE, Railway Technical Research Institute
Yuto Ono, AMIRSE, Railway Technical Research Institute
Takashi Toyama, AMIRSE, Railway Technical Research Institute

SUMMARY

We propose interlocking devices to be separated from field devices in order to reduce the cost to replace and to resume the interlocking functions fast, while most of the current interlocking devices are installed at stations. Interlocking functions will be realized as interlocking centre under cloud computing environment, which can be relocatable and distributed.

We first show an image of interlocking device with cloud computing environment, in which a new service model "Interlocking as a Service" is provided. We also discuss advantages and disadvantages of the system. Especially the interlocking devices are expected to be resilient when the interlocking centre is placed where it is safe against disasters. Then we propose some technologies to realise the system, including scalable architecture of interlocking device, management of field devices and interlocking logic suitable for the system.

We expect that our proposal will change operation and maintenance of railway and open a new operation model.

1 INTRODUCTION

Most of interlocking devices are installed at stations and directly connected with track circuits and point machines. When interlocking devices are severely damaged by lightning and/or disasters, it takes a lot of times to resume the interlocking functions. In addition, when an interlocking device is being replaced to a new device, a lot of works are required to change connections from the old device to the new one and to verify their connections. These maintenance and replacement works will be especially difficult for the small railway company. A new mechanism which is sustainable for small railway companies is required.

To reduce the cost to replace and to resume the interlocking functions fast, we propose interlocking devices to be separated from field devices. Then, interlocking functions will be realized under cloud computing environment called interlocking centre. Interlocking devices can be distributed. When the interlocking centre is placed at safe place against the disaster and/or redundant, the interlocking devices are expected to be resilient to the disaster. And new business model "Interlocking as a Service" will be possible.

In this paper we discuss advantages and disadvantages of the system, then we propose the structure of interlocking device in the cloud computing environment.

2 CLOUD COMPUTING ENVIRONMENT

2.1 Cloud Computing Service

Cloud computing service is a kind of service to provide computing resource making use of networking technology, in which programs and data are provided by servers. The word "Cloud" is used to emphasize that the service is provided without notice of location of the servers.

There some kinds of services.

- SaaS (Software as a Service) : Software is provided over network.
- PaaS (Platform as a Service) : Platform to execute software, which is prepared by users, is provided.

- IaaS (Infrastructure as a Service) : Hardware is provided over the network. User prepares not only software, but also operating system.

We suppose that the interlocking function with cloud computing environment is provided like SaaS, in such a way that software including interlocking functions works at cloud computing environment, and user can only send interlocking table or diagram to the software. We call this style of service “Interlocking as a Service”.

2.2 Interlocking Device with Cloud Computing Environment

We draw an image when “Interlocking as a Service” is realised as shown in Figure 1. Logical parts of interlocking functions, currently distributed at each station, are collected to “Interlocking Centre.” The interlocking centre is relocatable and can be placed where it is stable against disasters. When the networking condition is affordable, the interlocking centre can be distributed, which increases robustness against disasters. Large railway operating companies have their own interlocking devices and receive benefit of easiness to replace and robustness against disasters. On the other hand, small railway operating companies, who do not have their own device, receive “Interlocking as a Service” from large railway operating companies or service providers including signal device suppliers. Some large railway operating companies receive fees from small companies, which means that it is possible to gain money from their own equipment.

Field equipment such as track circuit devices and point machines are connected over network. Two kinds of connections are considered; one is in such a way that the equipment is connected to terminals with network interface installed at signal house. The other is in such a way that each device has its own network interface and is directly connected to the interlocking centre. In this case existing connection between devices and signal house will be changed into network cables, and the main function of signal house will be hub and power supply. It is even possible to connect terminals and devices via radio.

In spite that the logical parts of interlocking functions are located at interlocking centre, maintenance work will remain for field devices. Therefore, it will be ideal that monitoring functions on equipment are also implemented in cloud computing environment. If both of the interlocking functions and the monitoring functions are implemented in cloud computing environment, total management of signalling equipment will be realised.

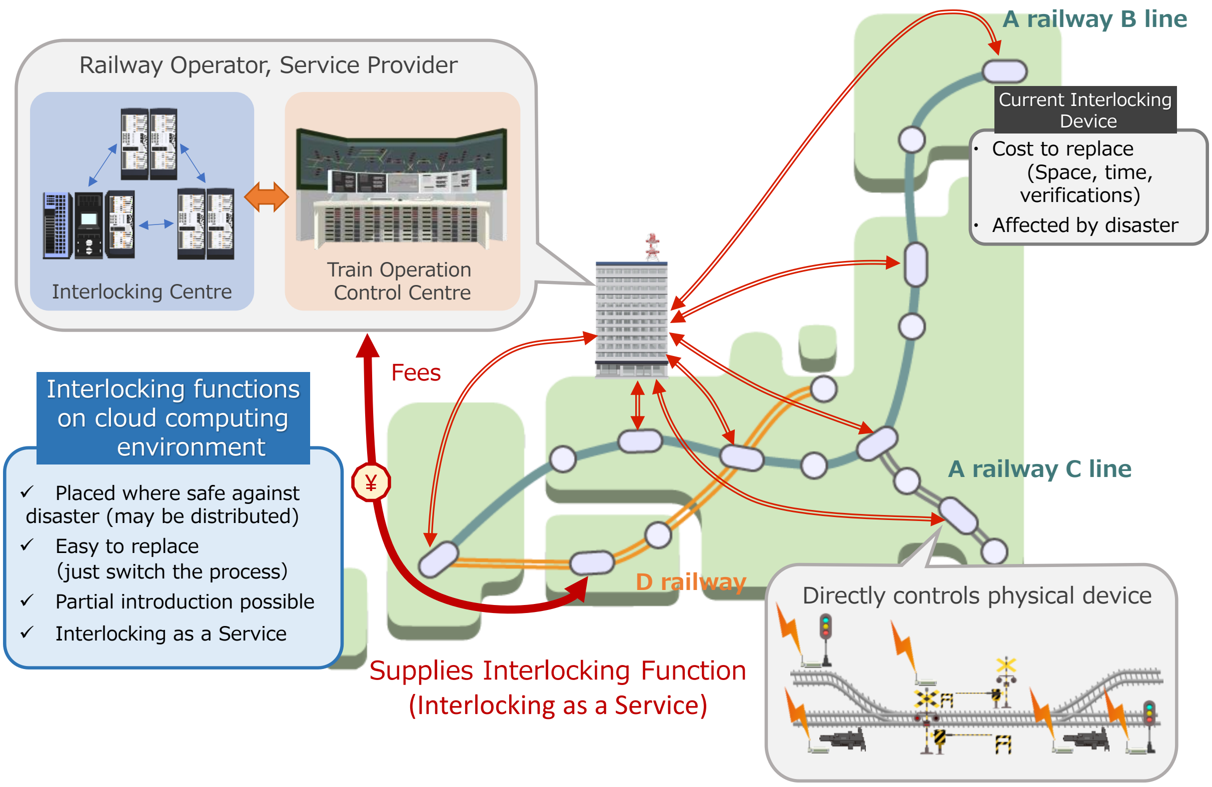

Figure 1: Image when “Interlocking as a Service” is realised

2.3 Advantages of Interlocking Device with Cloud Computing Environment

We discuss the advantages and disadvantages of interlocking devices with cloud computing environment. Advantages are described as follows.

2.3.1 Reduction of Replacement Cost

It requires a lot of time and cost to replace interlocking devices. Especially when a solid-state interlocking device is replaced, a new device must be prepared and checked on its programs, and the connection with field devices must be checked. If the old device is discontinued, compatibility must be considered between the old device and the new device. On the other hand, when interlocking function process can change from one server to another, seamless replacement is possible. When interlocking functions are realised as processes on the server, life time of the interlocking device will not be worried more.

2.3.2 Reduction of Signalling House

It is easily understood that it requires smaller space at stations for interlocking device with cloud computing environment than for relay based interlocking device. In addition, this system can reduce connections between devices, which results in the smaller space than for solid state interlocking devices.

2.3.3 Resilience against Disasters/Accidents

When the logical part of interlocking functions are placed where it is free from disasters, it will be easier to repair the interlocking function of a station as the logical parts will be safe when a disaster and/or accidents happens at the station. Even if the signal house is severely damaged, it will be enough to repair the terminals and connections. In addition, degraded repair will be available with radio when cables between terminals and devices are damaged.

2.3.4 Interlocking as a Service

This technology enables a new business model "Interlocking as a Service." Especially for small railway operating company, it is possible to be free from maintenance and replacement of signalling device, which results in reduction of the human resources.

2.3.5 Standard Package of Interlocking Function

If configurations and interlocking tables for small sized stations are standardised, standardised interlocking function can be provided with reduced fees. In some case, track circuits, point machines and signals must be arranged in accordance with the standardised interlocking function, but it results in reduction of costs. Of course, large railway operating companies can customise interlocking functions for their own layout of stations.

2.3.6 Compatibility with New Train Control Systems

This paper supposes that the train control system is traditional, i.e. trains' positions are detected with track circuits, and signals are indicated based on fixed block systems. However, when all of the field devices are collected at interlocking centre, it will be easy to shift train detection systems from track circuits to on-board detection. This means that interlocking functions on cloud computing environment have potential to ease the change of train control systems from track circuit based fixed block systems to on-board position detection and moving block systems.

2.4 Disadvantages of Interlocking Device with Cloud Computing Environment

We should also mention the disadvantage of Interlocking device with cloud computing environment.

2.4.1 More Influence Caused by Troubles

When a trouble happens at interlocking centre or network, more stations are considered to be influenced by the trouble. To reduce the influences, redundancy should be adopted. However, if there is a bottle neck, the bottle neck results in the weak point of the systems.

2.4.2 Sustainable Service

When a company receives service from service providers, there is an issue whether the provider gives service continuously, especially when the interlocking centre can be operated by general IT providers. If the service provider easily suspends the service, the small railway operating company suffer from sustainable operations. Railway companies have social responsibility on train operation. Therefore, some legal framework to sustain the interlocking centre will be required.

2.4.3 Security

Especially when open network and/or radio communications are used between field devices and logical parts of interlocking devices, security must be considered. On the other hand, service provider can provide more security than in case small company take attention of security by themselves. Even in closed network, security must be considered, because invalid access can be tried on the terminals, and external connections are possible from a terminal.

2.5 Existing Technologies

In this section we describe preceding technologies.

2.5.1 Network Signaling System

East Japan Railway Company has developed network signalling system in order to reduce installing procedure, in which optical fibres are used to connect between field devices and the interlocking device in signal house. In this system signal device and point machine have network interface and its own ID.

This concept resembles well to the proposed interlocking device with cloud computing environment. The major difference is that the interlocking device in the network interlocking is still installed at the stations. When the processing units of the network interlocking are moved to the central place, it will be a variation of our proposal. However, additional requirement will be required to handle more stations than currently used lines.

2.5.2 Centralised Interlocking

Some company has already introduced centralised interlocking device, in which interlocking functions of several stations are implemented on a single interlocking device. In the extreme example, all of the interlocking devices of a whole line are implemented on a single device. However, when interlocking functions of several stations are implemented as a single interlocking system, it encounters some problems on replacement and maintenance work. Even if only one station is changed its configurations, all other stations must be suspended their operations.

3 THE ARCHITECTURE OF SCALABE AND RELOCATABLE INTERLOCKING DEVICE

3.1 Proposal of Scalable Architecture of Processing Unit

Observation of existing technologies reveals that the current interlocking devices can process interlocking functions of several stations at once. However, the observation also reveals that there are some problems on maintainability when interlocking tables of several stations are summarized and treated as a large single table. It is important to process the interlocking table of each station independently, which enables to change configuration of one station without affecting other stations. In addition, the process to execute interlocking function should be relocatable, which prevents interlocking functions from stopping. If these two characteristics are realised, it leads to scalable and relocatable architecture of interlocking functions, i.e. processing units to execute interlocking functions can be added in accordance with the capacity of the interlocking functions. In this section we propose a scalable and relocatable architecture of interlocking processing units.

Securing fail-safe is necessary. We suppose to use fail-safe functions of current processing unit at the moment, which is practically implemented.

3.1.1 Observation of Current Process of Interlocking Function

Figure 1 shows an example of the process of current interlocking devices. Currently, checking input/output occupies a large part of the process cycle while processing interlocking function is relatively small. There is a limit on number of inputs/outputs which can be processed by current processing unit. On the other hand, when checking of inputs/outputs is executed by terminal placed at signal house or on site, it releases the capacity of processing unit at interlocking centre. Instead health of terminals is checked based on communication between the field device and interlocking centre.

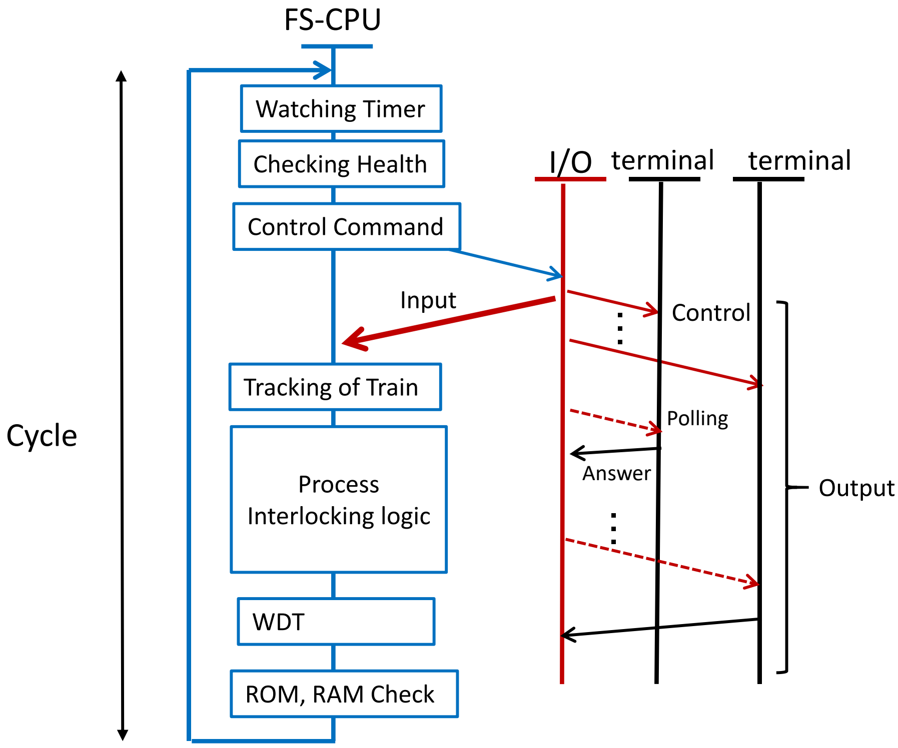

Figure 2: Current cycle of processing interlocking functions

Checking health of the processor, ROM, RAM, .etc. is common process and requires fixed capacity regardless of the size of interlocking table. On the other hand the processing unit is capable of processing larger interlocking functions than the current functions.

According to the following observation, we conclude that we can consider the scalable structure based on current processing unit.

3.1.2 Segment Based Processing

Based on the observation in the previous section, we propose to divide the cycles of the processor into segments as shown in Figure 3. A segment stands for a certain capability of processing. The number of segments that one processing unit can process differs depending on the capacity of the processor. In Figure 2, for one segment is used to process interlocking function of Station A, while two segments are used for Station B. The common procedure includes checking the cycle, input/output and memories.

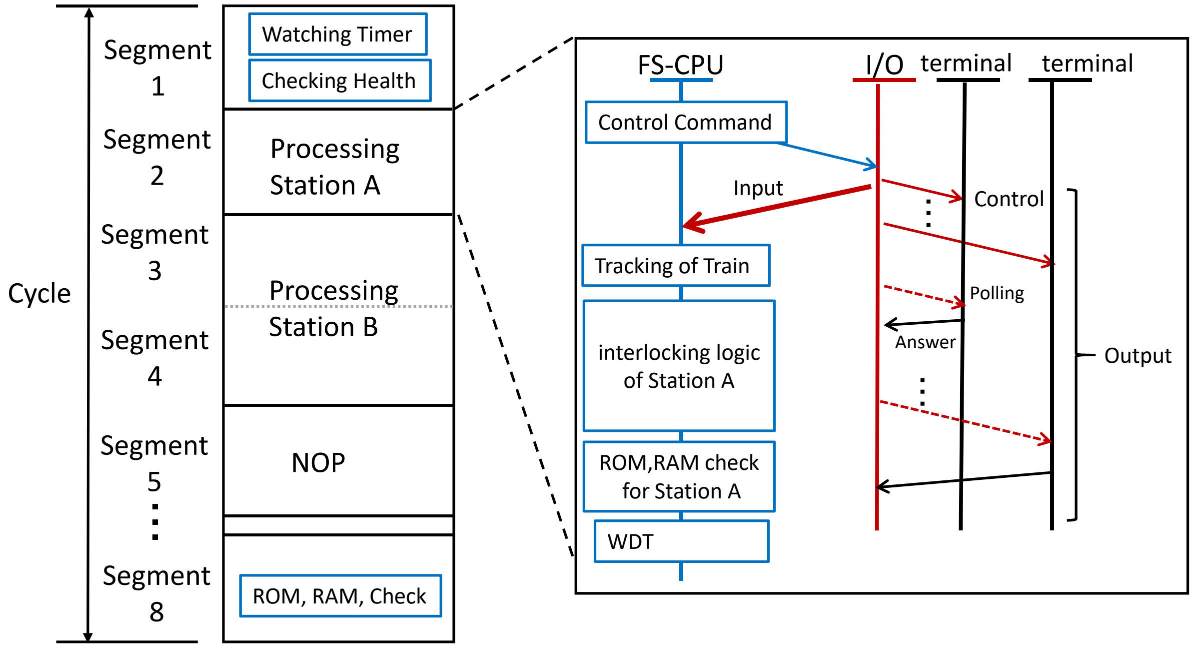

Figure 3: Segments of a Processing Unit

3.2 System Architecture to Realise Segment Based Processing

Data of the interlocking functions including interlocking table or diagram is stored at non-volatile memory of each processing unit. In order to control the data of the processing units, we propose controllers which control processing units. Controllers upload data of the interlocking functions to the non-volatile memories of processing units. Controllers also allocate the segments of processing units to the processes of the interlocking functions, and work as load balancer. One controller controls one or some processing unit, and the controllers co-operate each other. The relationship between controller and processing unit is shown in Figure 4.

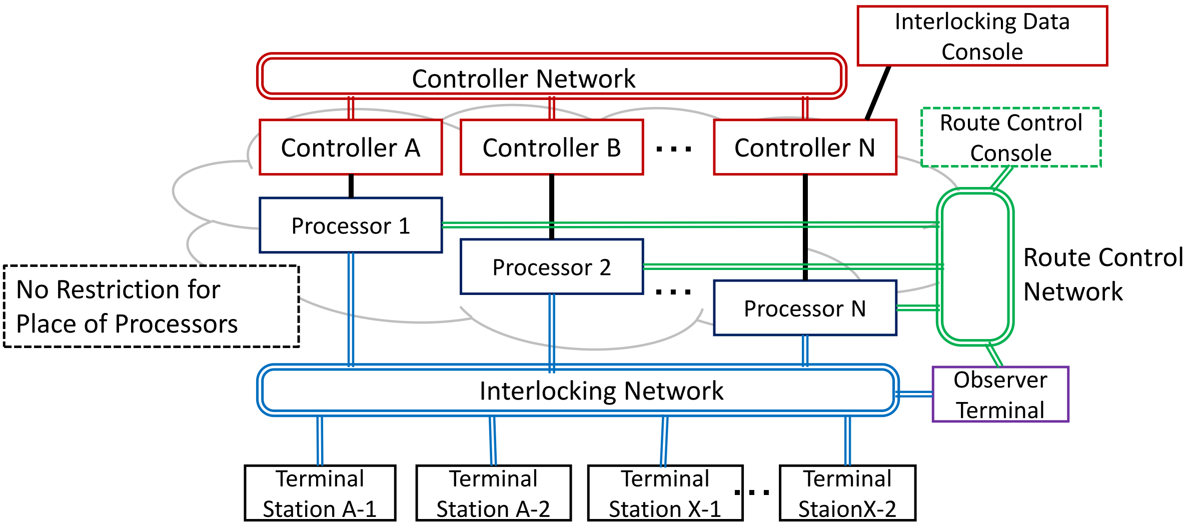

Figure 4: Architecture of a Scalable Interlocking Device

The data of interlocking functions and allocation tables of segments should be shared and consistent among controllers. To manage the data consistent, one of the controllers is selected and acts as the master controller. There are some options to select the master.

For example, we can use a token and the controller who catches the token becomes a master. The master controller collects the version of data other controllers have and broadcasts the collected version information to the other controllers. Then the controller who has the latest data broadcasts its data to the other controllers.

Controllers monitor the liveness of processing units under control. In addition, controllers monitors the liveness each other. If the master controller is not healthy, the token is forcibly collected, and another controller is selected as the new master.

Concerning with the strategy how to allocate segments, general strategies of allocating computational resources are applicable, therefore we will not discuss. However, we must estimate the number of segments required to process the interlocking functions of each station. It may be required to estimate the segment by executing the test process before the process is put into real operation.

3.3 Delay and Interlocking Logic

As proposed system uses network as an important component, we must consider the delay and deletion of information over the network. When the timeout is strictly and synchronously managed and system halts in case only one of the terminals does not respond within the timeout, there is no change in interlocking logic from conventional systems. However, when the timeout is short and managed strictly, requirement of network reliability will be too severe. On the other hand, the timeout is too long, it results in the reduction of performance. Therefore a new method is required in which the more delay is taken into account.

Some interlocking logic expects the inputs to be in order. If the order of the input is changed from the expectation, the output may be different from the expected result. To solve this problem, we can use time stamps and/or sequence number to the inputs; the inputs are sorted according to the time stamps and/or sequence numbers. However, when the logical calculations are waited for all of the inputs are determined, it causes the delay. Therefore we propose asynchronous movement between interlocking logic and field devices. Asynchronous movement is composed of asynchronous communication and asynchronous calculations.

For the asynchronous logic, three value logic considering indeterminacy such as Kleene's logic may be applicable. Table 1 shows an example of data table to realise asynchronous communication. "Input Time" indicates the latest input received and "Adopted Time" show the latest data adopted as inputs. "Output time" is the time for output relay. In case of 21TPR and 5OTPR, adopted time is 0:00:15 while input time is 0:00:16, because 5CTPR is delayed and the latest time is 0:00:15.

Table 1 Example of Data Table of Interlocking Logic

Relay	State	Adopted/Output Time	Input Time / Seq. No.	
21TPR(input)	Down	0:00:15	0:00:16	5
5CTPR(input)	Up	0:00:15	0:00:15	4
5OTPR(input)	Down	0:00:15	0:00:16	5
8FSR(output)	Up	0:00:16	-	-

We expect that this strategy will affect interlocking logic as little as possible. In order to consider the case when the device is not alive, timeout is settled. The timeout can be independently set for each device. Currently, we checked whether this strategy is effective on some implementation of interlocking elements. We will further study whether this is effective for other logics.

3.4 Management of Field Device

When control information is sent to field devices, each of the field devices must be addressable. There are two strategies for managing and information of IDs.

In the first strategy, interlocking centre manages all of the field devices, i.e. each device has a unique ID directly addressable by interlocking centre. Routing table is also managed by interlocking centre. In this case control commands are sent directly to each device independently by unicast message. However, when the whole network becomes huge and many devices are connected, broadcast message is not practical because network bandwidth is occupied by all of the messages at any place.

In the second strategy, interlocking centre only manages the ID of stations (or a group of stations) while the field devices are managed by interim ID in the interlocking functions. The terminal at the station has the translation table to determine the actual device by the interim ID. Control messages to the field devices are packed in a unit of station. From the control message, the terminal controls the device according to the translation table. In this case the field devices are not necessarily directly connected to the terminal. If the field device is connected to the terminal over the network, it is enough that the terminal has the function to determine the address of the field device from interim ID, and the terminal can only send message within the station network while the field device has the address of the terminal and send messages to the terminal over the network.

3.5 Bandwidth of Network

We studied on the bandwidth of network with a case study whether the concept of the interlocking device over cloud computing environment is possible from the view point of bandwidth.

Suppose the number of devices are 100,000, which is well correspond to the devices all over Japan. Suppose that each of the 100,000 devices sends 300 bits of data at each cycle and that the bandwidth is 10Gbps, the required time to send data is calculated as 3ms. This is enough to process the data in e.g. every 100ms. We think that the network is not necessarily the bottle neck of the interlocking device over cloud environment.

Please note that when monitoring functions of field device are implemented, the bandwidth will rapidly increase as monitoring data is often requires several bits.

4 FURTHER DISCUSSION

4.1 Securing Fail-safe using General Purpose Processors

Securing fail-safe is very important when logical parts of interlocking functions are processed. Currently in Japan input/output of dual processor are compared by comparator, which has a fail-safe characteristics itself and is controlled to the safe state when a failure happens. To do the same way in cloud environment, the processing units should be implemented with current fail-safe processing unit as indicated in section 3.1. However, it will be less cost effective.

To reduce the cost of the processing unit, technologies which use general processor and secure fail-safe using computational resources are required. It will be considered that multiple processes at different kind of processors are to be compared, in which the difference among the calculation results are obtained must be considered. A new comparison method must be implemented.

Another technology is possible to secure safety when terminal device, which will use fail-safe device, to check the health of interlocking centre.

4.2 Security

Security technology changes rapidly, and it will be difficult for railway operators to develop original security technologies. Therefore, the security technology should be selected according to the trend and security levels. In case “Interlocking as a Service” is provided, service providers maintain the security and use security specialised resources, which will be difficult for small railway operating companies. On the other hand, when a large operating company uses the logical parts of interlocking functions by itself, security must be considered by itself.

4.3 Possibility of “Interlocking as a Service”

In this paper we discuss only from the technical point of view. Many considerations and studies are required until a business model of “Interlocking as a Service” is commercially established. To provide “Interlocking as a Service” under public framework is another possibility, because now in many cases, especially in Europe, train operation companies and infrastructure management companies are divided and the latter is in many case operated in publicity.

5 CONCLUSION

We propose that the logical parts of interlocking functions are to be separated from physical devices at station and implemented under cloud computing environment. In this system the cost of replacement will be reduced, and the system will be resumed fast when disaster or severe accidents happens. In addition, this system has a possibility to change the maintenance of signalling systems, and enables "Interlocking as a Service." In other words, small railway operating companies will receive the service from service providers and reduce the human resources.

To realise interlocking functions over cloud computing systems, we proposed some technologies, including scalable architecture of processing unit, management of field device, and some change of interlocking logic in which some delays are accepted.

In order to realise "Interlocking as a Service," not only technical break through are required, but also analysis from economical point of view is required. However, we think that large railway operating company will receive benefit from these technologies, and proposal from these kinds of view will increase gradually.

6 REFERENCES

:

1. Miura, H., Hirano, Y., Kogure, G., Nishiki, A., *Introduction of Network Signaling to the Keiyo Line*, pp.1-4, Japanese Railway Engineering, No.175, 2012
2. Tatumoto, J., Toyoma, T., Omori, T., *A study on an Electronic Device which Allows for Asynchronous Operation between the Interlocking Logic Unit and the Field Devices,* Technical Report of IEE, no. TER-18-060, 2018 (In Japanese)