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RESEARCH ARTICLE

# Development and Evaluation of Augmented Reality Learning Content for Pneumatic Flow: Case Study on Brake Operating Unit of Railway Vehicle

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**ABSTRACT** The Brake operating unit (BOU) of a railway vehicle is one of the important systems for controlling the braking of the train. Because this system uses compressed air, it is difficult to understand and train the system. The existing education method involves learning the pneumatic flow of various control air in a 2D pneumatic circuit diagram based on a maintenance manual. However, in the actual braking system, it was difficult to learn effectively because the air flows in 3D. In order to solve these problems, the improvement of the training technique using the new 3D augmented reality (AR) was performed. In this study, to increase the learning effect of air brake flow, a technique for simultaneously displaying the pneumatic flow in 2D circuit diagram and 3D model was proposed. First, the distance ratio for simultaneous display can be determined using the proposed streamline matching variable calculation algorithm (SLMVC) that uses position and animation duration as input variables. Second, to avoid the complexity of using the 24 variables of the Particle System module in Unity, an existing universal 3D platform, a continuously emission property correction algorithm (CEPC) that can output particle objects as a streamline using only 4 properties (e.g., start lifetime, start speed, emission rate over time, start delay). As a result, the following 6 different types of BOU air pressure could be simultaneously displayed in 2D and 3D (e.g., AC, BC, SR, SBR, AS1, AS2). Therefore, maintenance staff can effectively learn complex pneumatic flow. To verify the usability of the developed content, a survey using the NASA-TLX technique was conducted targeting 60 maintenance staff. As a result of the comparison between Group A using the existing maintenance manual and Group B using the developed AR content, the perceived workload decreased by 28%. In particular, the frustration part decreased by 64% and the performance part decreased by 62%, indicating that the usability of AR content was very good.

**INDEX TERMS** Railway vehicle, augmented reality, brake operating unit, pnematic flow, particle effect.

## I. INTRODUCTION

The main objective of the fourth industrial revolution is to increase work efficiency and productivity in the working field. Technologies such as the internet of things (IOT),

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artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) represent the fourth industrial revolution. Among these, AR is a technology that allows to experience virtual images in the real world and real time and used in various industrial fields.

Railway vehicles prioritize the safe transportation of passengers and freight. A brake system that decelerates or stops trains is one of the key safety system. As the operation speed of railway vehicle increases, the deterioration of braking performance causes catastrophic damage to train operation. Therefore, securing the stability and reliability of the braking system has become important. Traditionally, railway vehicle manufacturing companies provide manuals for the function and maintenance of vehicle components in a booklet-type format. Railway operating organizations are conducting group education using these booklet-type manuals for job training of maintenance staff. However, this training method finds it difficult to not only manage time and space, but also manpower operation [1]. It is not suitable for learning the invisible and complicated electrical and pneumatic flow, because electric and pneumatic circuit diagrams provided in existing manuals are 2D. Additionally, it is difficult to understand 3D real mechanism of the actions between a device hierarchy. Recently, railway operating organizations are facing the problem of aging maintenance staff. The existing skilled staff are very old, and the proportion of novices is rapidly increasing [2]. Accordingly, the importance of systematic maintenance education is emerging. Therefore, to enhance the training effect of maintenance staff as well as overcome the shortcomings of booklet-type manuals, developing 3D learning content using AR technique is essential [3].

### A. RELATED WORK

AR content is being continuously developed and used in various industrial fields. Lalick and Watorek developed an algorithm that can collect data and detect mechanical defects in wind turbines using AR goggles [4]. This algorithm simplifies the maintenance process of a wind turbine and provides an accurate monitoring system. Sample tests showed that this algorithm can detect turbine faults with an accuracy of over 90%. Chounchene et al. proposed an AR framework for visual inspection in the automotive industry [5]. This framework visualizes data using AR technique and visually shows the inspection process of a production line. The results of the feedback obtained from users showed that using this framework can reduce operating costs. Peng et al. proposed an aviation equipment maintenance training program combining AR and AI technology [6]. This program implements the maintenance processes of a turbofan and landing gear in a simulation. Additionally, standardizing the maintenance procedure reduces the human error rate. Klimant and Kollatsch developed an application that efficiently supports engineers in maintaining machine tools [7]. Unlike a booklet-type manual, this application highlights the actual maintenance locations of machine tools within AR. Using this application, a maintenance manual can be distributed efficiently, and engineers can indirectly experience an actual work process.

Several studies have been conducted to verify the effects of AR content. Kim et al. investigated the effects of head-worn display (HWD)-type and user interface (UI) designs on staff experiencing a warehouse environment in the simulation of an order-picking process [8]. They conducted National Aeronautics and Space Administration-Task Load Index (NASA-TLX), Workplace Cognitive Failure Scale (WCFS), Usability Satisfaction Questionnaire (USQ), and Simulator Sickness Questionnaire (SSQ) surveys on participants in their experiments. The results demonstrated that using an HWD increases work performance and reduces cognitive workload. Atici-Ulusu et al. showed that automobile assembly lines using AR technology can reduce the NASA-TLX score by 10% compared to the conventional method [9]. They conducted 60 experiments on automobile assembly lines to investigate the cognitive load on employees. The results showed that the use of AR glasses has a positive effect on this property. Alves et al. conducted a preference survey for two environments (e.g., mobile and spatial AR) applied to assembling procedures [10]. They implemented a prototype that guided an actual assembly procedure and asked participants to respond to a questionnaire after performing this procedure. The results showed that a spatial AR environment leads to a higher work speed, fewer errors, and lower cognitive load than a mobile AR environment.

AR contents using mobile devices have been developed in various fields. An industrial AR maintenance application was developed to minimize content generation costs and assist technicians in daily tasks [11]. A remote maintenance platform that implements the process of replacing an industrial robot's battery pack with AR has been developed. On this platform, users can record feedback on mobile devices [12]. Bordegoni1 et al. developed applications by combining mobile and AR technology to support remote maintenance of industrial products. They explained that the application could reduce travel expenses and increase service quality [13]. Konstantinidis et al. demonstrated the maintenance steps of the a/c compressor using a mobile application created with Unity and evaluated it with experts. They announced that it could close the time gap between experienced maintenance managers and not very experienced staff [14]. However, most of the current mobile-based AR content studies have implemented a simple maintenance work process [15], [16], [17].

In this study, not only hierarchy but also the pneumatic flow of brake system are implemeted in AR. Additionally, to verify the usability of AR content, a group experiment was conducted to complete the evaluation sheet containing essential information that BOU maintenance staff must know and NASA-TLX survey.

### B. RESEARCH BACKGROUND

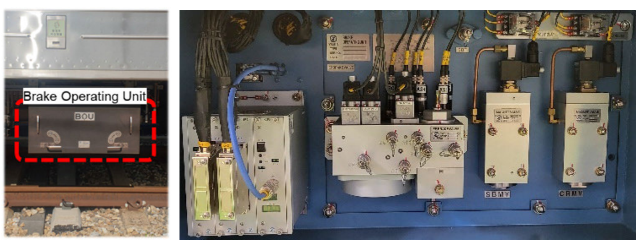
Various studies have provided AR content as an alternative to existing booklet-type manuals. However, thus far, they have been limited to mechanical assembly and maintenance procedures. Moreover, efforts to change complex 2D circuit diagrams of electrical and mechanical devices into 3D forms using AR techniques have been insufficient. In the railway vehicle field, AR has been limited applied to predictive maintenance and development of a framework that supports a maintenance process [18], [19]. The pneumatic flows of the brake system for railway vehicle are complex and invisible to the naked eye. Therefore, theoretical education using 2D drawings has limitations in understanding the flow. The present study aimed to develop learning content that arouse interset of the trainees and increase educational understanding by showing the pneumatic flow of BOU on one screen in 2D circuit diagram and 3D model. Users learn the pneumatic flow and hierarchy of BOU in AR using personal mobile devices. The usability of AR contents was verified by analyzing the quantified perceviced workload obtained through the NASA-TLX survey.

## II. METHODS AND MATERIALS

### A. BRAKE OPERATING UNIT

A BOU controls the air to be supplied and exhausted from a basic brake system according to electric commands when brake is applied and released, respectively. As shown in Figure 1, a BOU consists of 6 subcomponents related to the brake system, each of which has a modular structure with various ports and valves. There are 6 different types of pressure in the brake system.

1) AC: application control pressure of the change valve.
2) BC: brake application control pressure output from the brake cylinder.
3) SR: compressed air pressure stored in the supply reservoir.
4) SBR: compressed air pressure stored in the security brake supply reservoir.
5) AS1: air spring pressure.
6) AS2: air spring pressure.

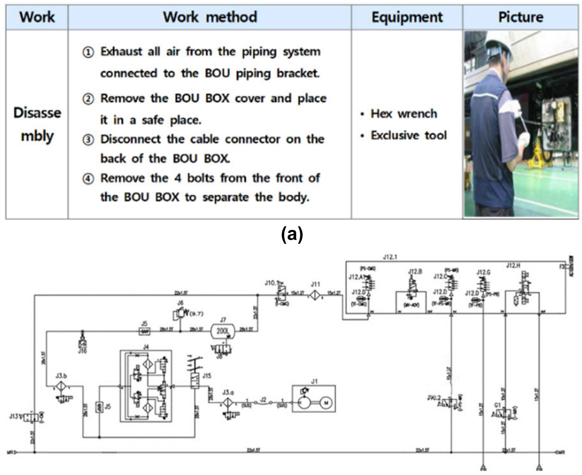



(a) (b)

**FIGURE 1.** Brake opearting unit: (a) external, (b) internal.

Pneumatic flows are supplied or exhausted by commands of different brake systems for each pressure. Thus, it is difficult to understand the mechanism of a BOU because the structure and functions are very complicated and the pneumatic flow varies by each pressure.

Most BOU maintenance education at railway operating organizations is conducted mainly based on textbooks, such as work instructions and circuit diagrams. In terms of the learning time, using work instructions as shown in Figure 2(a) is inefficient due to the use of descriptive sentences to explain the structures and functions of devices. The circuit diagrams as shown in Figure 2(b) are very complex and not practical for beginners because they are difficult to access.



| Work | Work method | Equipment | Picture |
|---|---|---|---|
| Disassembly | ① Exhaust all air from the piping system connected to the BOU piping bracket.<br>② Remove the BOU BOX cover and place it in a safe place.<br>③ Disconnect the cable connector on the back of the BOU BOX.<br>④ Remove the 4 bolts from the front of the BOU BOX to separate the body. | • Hex wrench<br>• Exclusive tool | |

(a)

(b)

**FIGURE 2.** Maintenance manuals of railway operating organizations: (a) work instruction, (b) 2D pneumatic circuit diagram.

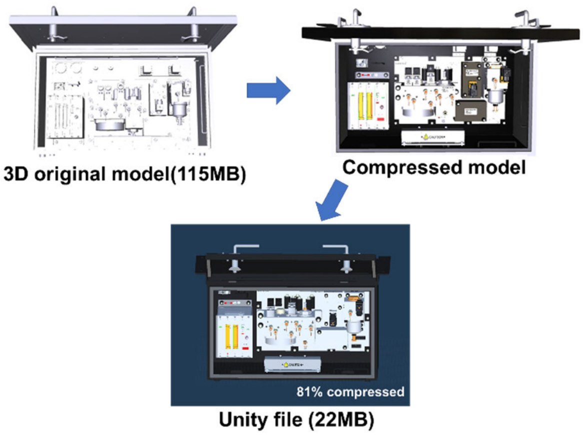



**FIGURE 3.** 3D high-polygon modeling process.

Additionally, it is problematic to learn only 2D pneumatic circuits because the complex air flow of BOU is difficult to discern with the naked eye. Therefore, developing AR content that displays a device hierarchy and a pneumatic flow in 3D forms to maintenance staff is important.

### B. AR LEARNING CONTENT

Digital content is produced in digital form to increase the utility of products that provide information to users [20]. Interest in new digital content has increased with the development of information and communication technology, and efforts have been made to connect it with learning [21]. AR provides an efficient way to convey information by overlaying such digital content in a real working environment. It also complements existing static content and enhances learning ability of users [22]. The implementation platform of AR is changing from computer to mobile environment. Recently, mobile devices have become diverse and widely owned, such as smartphones and tablets. It also plays an important role in modern education and has various benefits. Therefore, interest in integrating the benefits of mobile learning and AR applications has increased [23]. Mobile augmented reality (MAR) is defined as a system that combines real and virtual objects in a real environment, is interactive in real time, runs and displays the augmented view on a mobile device [24]. In this study, learning content for BOU was designed based on MAR system by integrating mobile learning and AR application.

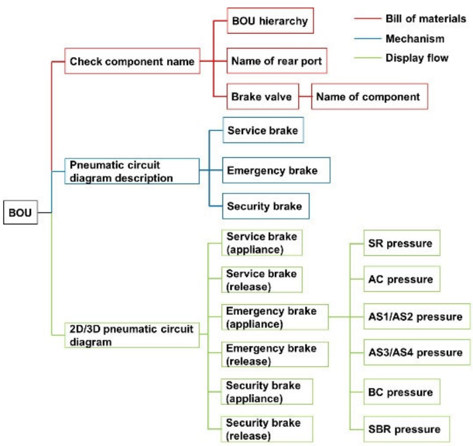



**FIGURE 4.** Mapping of the correlation between keywords in the BOU mechanism.

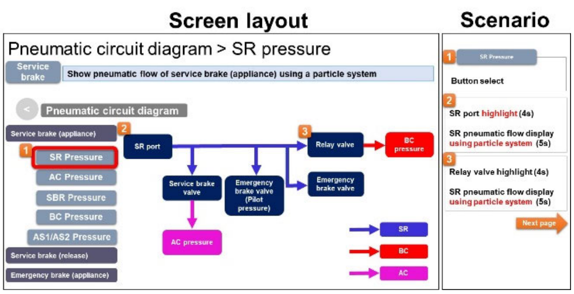



**FIGURE 5.** Example of a storyboard when clicking the SR pressure button.

## C. CONTENT DESIGN

### 1) MODELING

Figure 3 shows the 3D high-polygon modeling process of a BOU model for content development. This technique produces edges by connecting vertices that form the basic unit and generates 3D forms by combining faces formed by connecting the edges [25].

Therefore, a 3D object file is composed of several polygons. Because the data in such a model file are compressed by more than 80% compared to that in a computer-aided design(CAD) model, it has the advantages of fast loading and high accessibility when loaded on mobile devices. The file is built by using Unity [26], [27].

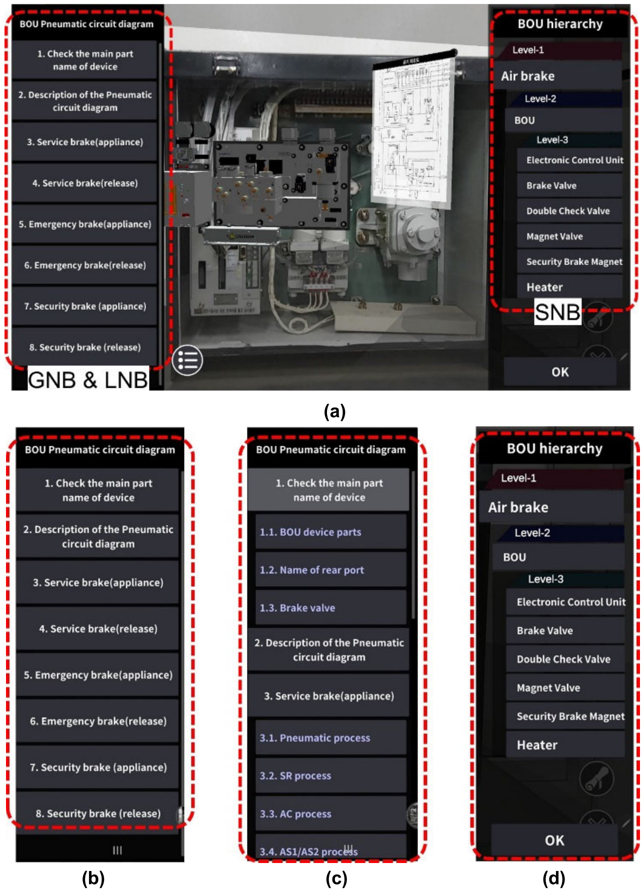



**FIGURE 6.** UI and menu bar format of AR content: (a) display form, (b) GNB, (c) LNB, (d) SNB.

### 2) LEARNING CONTENT DESIGN

Figure 4 presents the mapping of the correlations between the keywords in the BOU mechanism. The keywords for designing learning content subdivide information about the BOU, consisting of check component name, pneumatic circuit diagram description, and 2D/3D pneumatic circuit diagram. These keywords are subdivided into 12 subcomponents. Figure 5 is an example of a storyboard when clicking the SR presseure button. This shows the UI composition of the screen displayed when each button is clicked. Additionally, to show the pneumatic flow, the operating principle of the BOU is identified and compared with the pneumatic circuit diagram to detail a flow for each pressure. And the entire scenario is displayed, including phrase to be expressed in text form within the screen, the detailed function to be applied, and the duration of each animation, etc.

Figure 6 shows the UI and menu bar format of the AR content. As shown in Figure 6(a), the UI of this content consists of three parts: global navigation bar (GNB), local navigation bar (LNB) on the left, and side navigation bar (SNB) on the right. Figure 6(b) presents the main menu in the GNB and shows the content composition. Figure 6(c) displays the submenu in the LNB and shows the detailed contents depending on the choice of a user. Figure 6(d) shows the side menu in the SNB and presents the hierarchy of the system and location of each component. Furthermore, the UI is designed to output without distortion, responding to various screen ratios and sizes of mobile devices. This UI design increases the convenience of user operation by improving the readability of the menus.

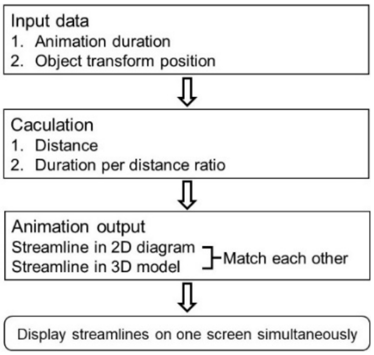


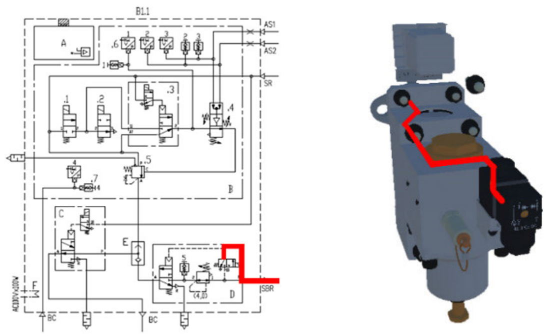

**FIGURE 7.** **Flowchart of the SLMVC algorithm.**

### D. PARTICLE SYSTEM

A particle system creates a visual effect by rendering extremely small images or meshes called "particles". This system is useful for implementing dynamic objects that are difficult to depict with meshes or sprites, such as fire, smoke, and liquids. Recently, many digital contents have used particle systems to depict special effect. However, these contents only implemented objects in 2D and 3D, respectively, and did not match and display them on a single screen. There was no content displayed on one screen by matching each object. Pneumatic flow of BOU is very complex, so it is difficult to set the direction individually to display flow as a particle and it consumes a lot of working time. Additionally, because it is impossible to discern with the naked eye, learning efficiency is low if only 2D data is used. In this study, two algorithms were proposed. These algorithms implement the pneumatic flow as a streamline in 2D, 3D and displays them by matching each other on one screen [28].

#### 1) STREAMLINE MATCHING VARIABLE CALCUATION ALGORITHM

Particles move in a single path within the circuit diagram, which is a 2D coordinate system. However, in the BOU model, which is a 3D coordinate system, it has various directions for each pressure. This study proposed a streamline matching variable calculation (SLMVC) algorithm that matches two streamlines in 2D and 3D coordinates by inputting only 2 values and outputs them simultaneously. Figure 7 is a flowchart of the SLMVC algorithm.



(a) (b)

**FIGURE 8.** **Streamline in each coordinate system: (a) 2D (b) 3D.**

Arrange the position by inputting the individual transform position values of the object. Also, input the animation duration, which is the time until the pneumatic flow reaches the final position. Depending on the 2 input variable, distances and duration per distance ratio are calculated by Table 1. Animations are output in 2D and 3D coordinate systems at the same speed according to the duration per distance ratio, which is calculated from the progress direction of each position. Therefore, it is possible to simultaneously display matched streamlines.

Figure 8 shows the streamline of 2D and 3D coordinate systems moving the same point according to the set time. Two streamline can be expressed simultaneously in 2D coordinate system as in Figure 8(a) and 3D coordinate system as in Figure 8(b). Because it passes through the same position value, it can be compared with each other in a matched state.

#### 2) CONTINUOUSLY EMMISION PROPERTY CORRECTION ALGORITHM

Prefab of Unity is a template made so that objects can be used repeatedly. Instantiate is to call and use these prefabs

**TABLE 1.** **Code of the SLMVC algorithm.**

**Input** : Animation Duration ***A***, Vector3 Position List ***P***[$P_{1(x,y,z)}$,$P_2$…$P_x$]
**Result**: Render lines in the order of position list **P** during animation duration A
**Start SetDistance**
{ **For** (i = 0 to length of ***P***-1, i++)**)**
Produce List of Distance ***D***, Calculate Distance and $\boldsymbol{D_1}(\boldsymbol{P_i}\text{-}\boldsymbol{P_{i+1}})$ …$\boldsymbol{D_i}$
$D_i$=Distance($P_i$, $P_{i+1}$))= $\sqrt{(P_{i+1x} - P_{ix})^2 + (P_{i+1y} - P_{iy})^2 + (P_{i+1z} - P_{iz})^2}$
Add Every D ($D_1$…$D_i$) to calculate Total Distance ***Total Distance***
Produce List Time per distance ratio ***L***

$$L_i = \mathrm{A} \cdot \frac{D_i}{TotalDistance}$$

End-**For**

$$L_i = \text{Animation Duration} \cdot \frac{Distance_i}{TotalDistance}\}$$

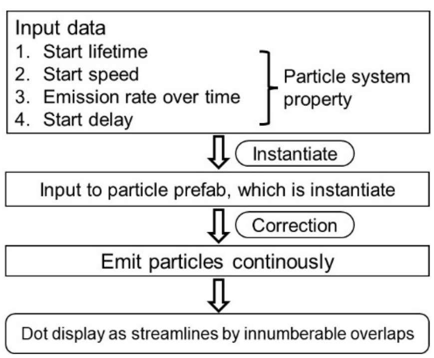



**FIGURE 9.** **Flowchart of the CEPC algorithm.**

**TABLE 2.** Code of the CEPC algorithm.

```
Start Instantiate Particle
{ Get Object Prefab, float Delay
  For (i = 0 to length of P-1, i++)
    Instantiate Object Prefab As a on P_i
    Rotate a to look P_{i+1}
    Set a.Particle System.Start Lifetime, Start Speed, Start Delay,
          Emission.rate Over Time
             Start Lifetime = L_i
             Start Speed = D_i / L_i
             Emission Rate iver Time = Start Speed
      Delay += Delay
  End For }
```

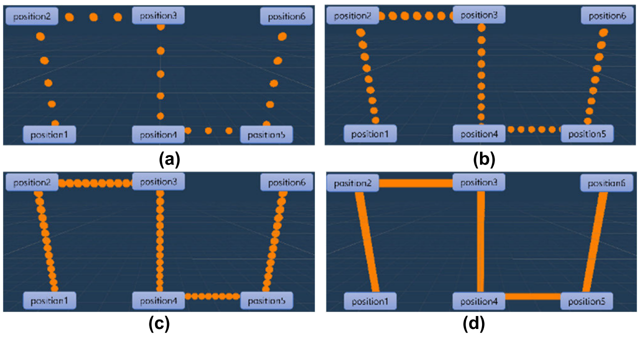



**FIGURE 10.** Process until the emitted particles displayed as streamlines: (a) fist step, (b) second step, (c) third step, (d) fourth step.

in real time whenever needed. To express the pneumatic flow in 3D, make a particle prefab with the properties of the particle system inputted and instantiate it. Modules of the particle system contain 24 properties that affect the entire system. To avoid the complexity of using variables, this study proposed a continuously emission property correction algorithm (CEPC) that can output a particle object as a streamline by inputting only 4 properties (e.g., start lifetime, start speed, emission rate over time, start delay). Figure 9 is a flowchart of the SLMVC algorithm.

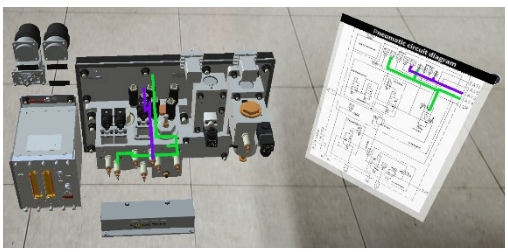



**FIGURE 11.** Service brake release (AC3, AC4 pressure).

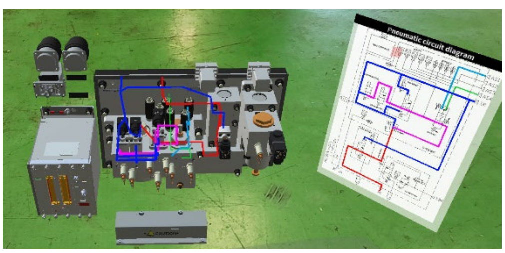



**FIGURE 12.** Service brake appliance (BC, SR, AS1, AS4 pressure).

Once each property is input, it is automatically corrected by Table 2 and subsequently input into particle prefab, which is instantiate. Instantiate the corrected particle prefab to continuously emit particles. Figure 10 shows process until the emitted particles displayed as streamlines. Dots is displayed as streamlines by innumerable overlaps through the process from (a) to (d).

### 3) IMPLEMENTING PNEUMATIC FLOW

The developed BOU content implements the movement and reach of each pneumatic flow when the service, emergency, and security brakes are applied or released using the particle system. Figure 11 and Figure 12 show the implementing pneumatic flows of the service brake AC3, AC4 pressures and BC, SR, AS1, AS4 pressures in the BOU model and its circuit diagram, respectively. Thus, users learn the pneumatic flows in a 3D form, which cannot be found in a booklet-type manual, by matching the 2D circuit diagram and the 3D model.

The SLMVC algorithm and CEPC algorithm proposed in this study display particles as streamlines by inputting the necessary dynamic object position, animation duration, and 4 particle system property values. Minimize the number of input variables and automatically calculate and output particle motion. This reduces work time, prevents erroneous input, and improves output reliability. The streamline flow implemented through this algorithm is useful when displaying not only the flow of complex

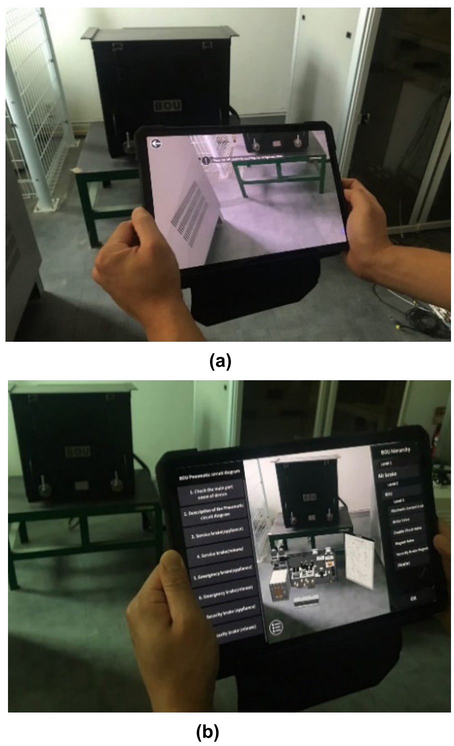



**FIGURE 13.** Makerless method of AR content: (a) screen to guide plane detection, (b) AR object is place on tablet screen.

**TABLE 3. Touch gestures to use AR content.**

| Change value | Corresponding touch gesture | Explanation |
|---|---|---|
| Position |  | Touch one finger to move model position |
| Scale |  | Touch two fingers to increase/decrease size of model |
| Rotation |  | Touch two fingers to rotate model |
| Position / Scale |  | Touch two fingers to move position and increase/decrease size of model |
| Position / Rotate |  | Touch two fingers to move position and rotate model |
| Scale / Rotate |  | Touch two finger to rotate model and increase/decrease size of model |

electrical and pneumatic circuit diagrams of railway vehicle devices, but also the invisible flow that exists in various industries.

(a) (b)

**FIGURE 14. AR content loaded on mobile phone: (a) emergency brake, (b) security brake.**

## *E. MOBILE-BASED EDUCATION*

Content completed according to the storyboard go through the build setting process to be used on mobile devices. Select a platform suitable for the mobile device to be used and execute the switch platform function. Then, it is converted into a file for mobile, and the content can be run on the mobile device using this file. Additionally, The AR content is based on the makerless method using the AR Foundation package of Unity. As shown in the Figure 13(a), users access the content by touching the plain generated on running the application. An AR object is placed on the screen of the tablet, as shown in the Figure 13(b). On the screen, an AR world is implemented in which the augmented BOU model can move in the real world. The position, scale, and rotation of the AR object are adjusted using 6 touch gestures, as listed in Table 3. Through these markerless and touch methods, users utilize the content at an actual work site using their personal mobile devices without additional equipment.

The research team conducted a pilot test on mobile devices for learning content. The goal of the test is to evaluate field applicability and performance. The sequence of test is to run the application and touch plain, and match the virtual BOU model with BOU in the real world. After that, check whether the 6 pneumatic flows are correctly displayed. Figure 14 shows the research team performing pilot training by loading the pneumatic flows of the emergency and security brake of a BOU on a mobile phone, respectively. As a result, it was possible to match the virtual BOU model with the BOU in the real world, the size and proportions of UI were displayed correctly. Also, particle effect and animation were output smoothly.

In this study, a mobile AR system based on the devices which have mobility is brought for maintenance education [29]. Therefore, as a mobile-based education method, learning content can be accessed from any mobile device [30]. Most of the existing AR contents required separate head mounted display (HMD) equipment such as AR glass, goggles and HoloLens [31], [32], [33], [34]. However, unlike manufacturing or simple repetitive maintenance work, railway vehicle maintenance work involves handling heavy weights [35], [36], [37]. Also, while parked in a railway vehicle depot, maintenance work is performed under the rails or on top of the car body. If HMD is used in this environment, staff have a risk of colliding with real space objects or slipping while working due to the limited field of view. This has a great impact on work safety [38], [39]. Meanwhile, existing maintenance staff are aging, they are not familiar with AR technology.

**TABLE 4. Information of experts.**

| Number of people | Information |
|---|---|
| 3 | Professional engineer railway rolling stock license holder |
| 3 | Professor of railway vehicle field |
| 4 | More than 30 years of experience in railway vehicle maintenance |

Therefore, in this study, AR was implemented on the mobile screen as the first step in introducing AR technology to the railway vehicle maintenance field. It provides a mobile-based education environment that allows easy access to learn content with personal mobile devices. Users learn about the hierarchy and pneumatic flow of the BOU more efficiently without time and space limitations than when using booklet-type manuals.

This content is produced at a fixed frame speed of 30 frame per seconds (FPS), which is a reasonable reference speed when producing a mobile platform with unity [40]. Therefore, it is recommended that user utilize content on a mobile device that supports at least 30 FPS.

## *F. AR CONTENT USABILITY VERIFICATION*

In this study, the participants were divided into two groups and the experiment was conducted to verify the usability of

AR content. Group A used a booklet-type manual and group B used AR content to study the hierarchy and pneumatic flow of the BOU. As the result data, evaluation completion time, number of correct answers, the perceived workload score were collected.

### 1) EXPERIMENT DESIGN

The experiment was conducted for four days. The University Industry-Academic Cooperation Foundation recruited 100 experiment participants. Among them, the participants were 60 railway vehicle maintenance staff who completed the consent procedures for data collection. Their mean age was 34.6 years (standard deviation: 5.2), the mean career length was 6.2 years (standard deviation: 2.3). Group A and B consisted of 30 participants each.

The evaluation sheet consisted based on the advice of 10 experts. It consisted of 12 questions for the participants to evaluate whether they recognized the essential competencies as BOU maintenance staff after studying. Table 4 shows the information of experts.

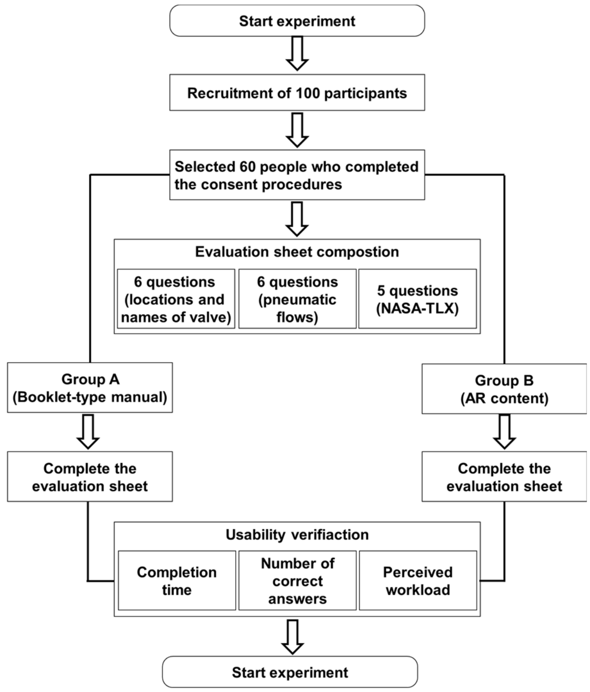



**FIGURE 15.** Flowchart of the experiment design.

**TABLE 5.** NASA-TLX survey questions.

| Part | Questions |
|---|---|
| Mental demand | How mentally demanding was the task? |
| Temporal demand | How temporally demanding was the task? |
| Performance | How successful were you in accomplishing what you were asked to do? |
| Effort | How hard did you have to work to accomplish your level of performance? |
| Frustration | How insecure, discouraged, irritated, or stressed were you during the task? |

Maintenance staff should know the exact locations and names of the components for the maintenance and overhaul works of a BOU. The participants had to write the name of the following 6 valves and their exact locations on an internal structure image of a BOU shown on the evaluation sheet. These are as follows:

1) Electronic control unit.
2) Main brake valve.
3) Double-check valve.
4) Magnet valve.
5) Security brake magnet valve.
6) Heater.

Maintenance staff must be well acquainted with each detailed pneumatic flow to determine the causes of the failure and fault of a BOU. The participants had to write 6 different pneumatic flows by color according to appliance/release and type of pressure on the two pneumatic circuit diagrams presented in the evaluation sheet. These are as follows:

1) Service brake release AC pressure.
2) Service brake release SR pressure.
3) Service brake release SBR pressure.
4) Service brake appliance BC pressure.
5) Service brake appliance AS1 pressure.
6) Service brake appliance AS2 pressure.

NASA developed the NASA-TLX survey. This method evaluates the perceived workload by dividing a questionnaire into 6 parts. There are various subjective measurement methods to measure the effect of AR on workload, NASA-TLX is the most common method [41]. The reliability and validity of the NASA-TLX as a measurement of workload has been demonstrated through widespread use in various research fields [42], [43]. In this study, the survey consisted of only five questions; it excluded the ''Physical demand'' question, which was unnecessary for this experiment. The responses to each question were defined on a 100-point scale from 5 (very low) to 100 (very high). Table 5 lists the questions for each

**TABLE 6.** Analysis of t-test results for all evaluation parts.

| Part | Group | Mean | StDev | SE mean | T-value | DF | P-value |
|---|---|---|---|---|---|---|---|
| Completion time | A | 546.66 | 34.62 | 6.32 | 1.96 | 58 | 0.55 |
| | B | 530.10 | 30.71 | 5.60 | | | |
| Component name | A | 3.86 | 0.77 | 0.14 | -3.15 | 58 | 0.003 |
| | B | 4.56 | 0.93 | 0.17 | | | |
| Pneumatic flow | A | 1.93 | 0.73 | 0.13 | -9.13 | 58 | $<0.001$ |
| | B | 4.16 | 1.11 | 0.20 | | | |
| NASA-TLX | A | 265.33 | 33.24 | 6.06 | 9.24 | 58 | $<0.001$ |
| | B | 191.83 | 28.11 | 5.13 | | | |

part. For each question, a high score implies a high perceived workload.

Before the experiment, the research team educated each group about the AR content, such as the menu organization and the touch method. They also informed each group that the experiment data would be collected anonymously and used only for research. Group A studied two aspects of the BOU hierarchy and the service brake appliance/release procedure for 30 min. This group used a detailed maintenance manual and a circuit diagrams of the pneumatic flows shown in different colors. Group B studied the hierarchy of the BOU and the service brake appliance/release procedure using AR content on their own mobile devices for 30 min. All participants were instructed to complete the evaluation sheet of 12 questions and the NASA-TLX questions. Figure 15 is a flowchart of the experiment design.

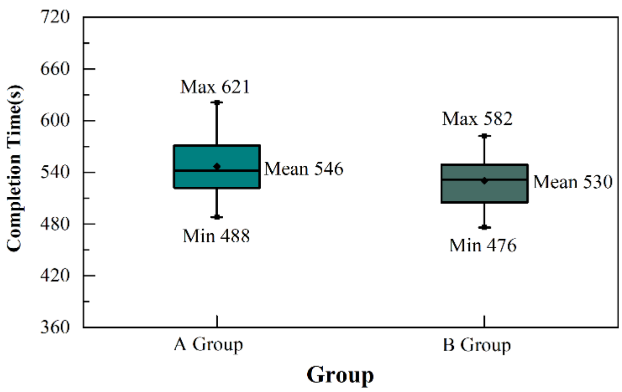



**FIGURE 16.** Box plot of completion time.

## III. RESULTS

A T-test analysis verifies the statistical significance between the mean scores of two groups [44]. In this study, a T-test analysis was conducted to confirm whether there was a statistical significance between the completion time, number of correct answers, and perceived workload of each group using SPSS, a statistical analysis program [45]. Table 6 summarizes the T-test analysis results of the evaluation data of each group. The results were the sample distribution of each score mean followed a normal distribution by the central limit theorem, because the data were collected from two independent groups and the sample size was more than 30 [46].

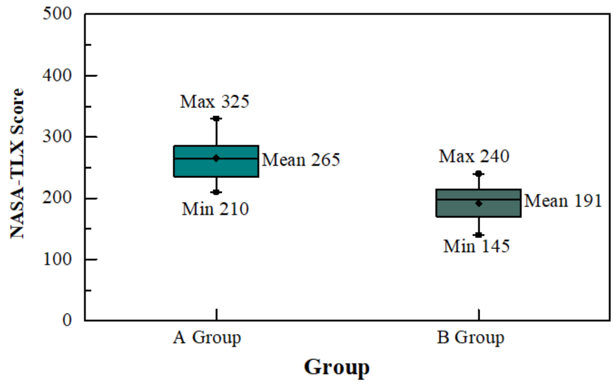



**FIGURE 18.** Box plot of NASA-TLX survey scores.

### A. COMPLETION TIME

Figure 16 shows the box plot of the evaluation completion time for each group. The mean completion time of group A was 9 min and 6 seconds, which was approximately 16 seconds shorter than that of group B, which was 8 min and 50 seconds. As a result of analysis for each dataset, the variance of the both sample was the same because the probability value (p-value) of the Levene's test was grater than the significance level (0.05) [47], [48]. However, there was no statistical significance in the mean completion time difference because the p-value of the T-test was greater than the significance level (0.05).

### B. NUMBER OF CORRECT ANSWERS

Figure 17 shows the number of correct answers for each group according to the evaluation part. In terms of the component name, group B (4.56) showed an 18% increase in the mean number of correct answers compared to group A (3.86). Regarding pneumatic flow, group B (4.16) achieved a 115% increase in the mean number of correct answers compared to group A (1.93). As a result of analysis for each dataset, the

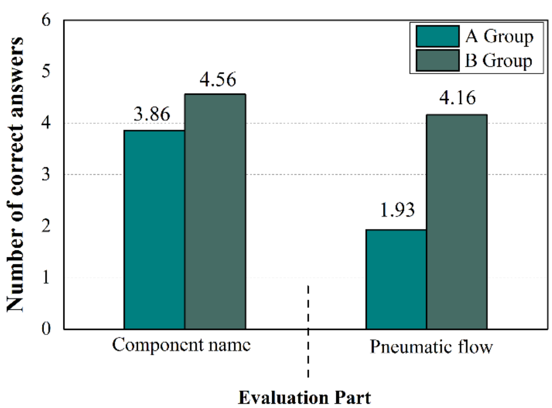



**FIGURE 17.** Bar graph of number of correct answers.

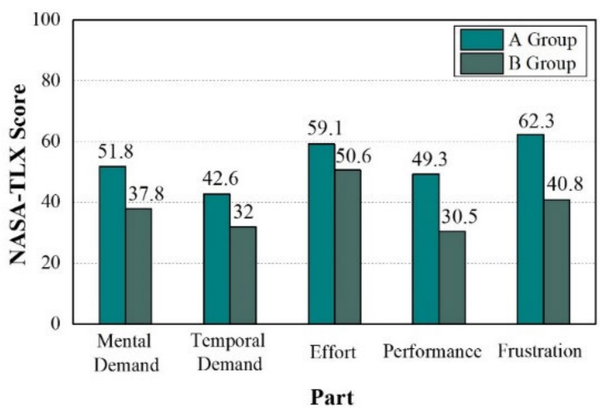



**FIGURE 19.** Bar graph of score for each NASA-TLX part.

variance of the both sample was the same because the p-value of the Levene's test was grater than the significance level (0.05). Because the p-value of the T-test was lesser than the significance level (0.05), the increase in the mean number of correct answers in group B was statistically significant. Thus, the use of AR content by maintenance staff to study essential competencies has a higher training effect than a booklet-type maintenance manual.

### C. PERCEIVED WORKLOAD

Figure 18 shows the scores of the NASA-TLX survey using a box plot. The minimum and maximum scores of group A were 210 and 325, respectively, and the mean score was 265.33. The minimum and maximum scores of group B were 145 and 240, respectively, and the mean score was 191.83. The mean score of group B decreased by 28% (74) compared to that of group A. As a result of analysis for each dataset, the variance of the both sample was the same because the p-value of the Levene's test was grater than the significance level (0.05). Because the p-value of the T-test was lesser than the significance level (0.05), the decrease in the mean score of group B was statistically significant. Therefore, the participants using the AR-implemented maintenance manual had a lower perceived workload than those using the booklet-type manual.

Figure 19 shows the score for each NASA-TLX survey part. The mean scores of group B for all 5 parts were lower than those of group A. For the frustration part, the mean score of group B was 40.8, which was 64% lower than that of group A (62.3), showing the highest gap. The participants in group B felt lesser stressed and burdened than those in group A because they could intuitively learn the pneumatic flows implemented in as streamlines with overlapping particles, which was not found in the booklet-type manual. For the performance part, the score of group B was 30.5, was 62% lower than that of group A (49.3). The performance part had the lowest score among the 5 parts.

The participants gained confidence in the evaluation because they could learn the pneumatic flows of the BOU by matching the streamline displayed at each position in the 2D circuit diagrams with the 3D model. For other parts, the scores of group B decreased by 27% for the mental demand, 24% for the temporal demand, and 14% for the effort.

### D. LIMITATIONS

In this study, railway vehicle maintenance staff were the targets in the experiment. However, there were no analysis results for older generation, who are relatively unfamiliar with AR technique, because this experiment was conducted with young participants. Furthermore, the experimental results can vary depending on the technology acceptance or the individual differences in the training ability. In future studies, it is necessary to collect experiment data not only from the older generation, but also from the all age groups. Based on this data, it has to be analyzed whether the learning effect according to content use differs depending on particiapnts' AR technology experience and learning ability by the age group. The research team will conduct various experiments like this in the future to find the most effective way to use AR content in railway operating organizations.

In addition, further investigation is needed on the effect of long-term using this content in an actual field workplace [41], [49]. Currently, the experiments for effect analysis were conducted under a controlled environment with pre-training. Therefore, the applicability of the content in the real environment must be closely observed and analyzed for a long-term without any intervention. Additionally, there are many variables such as manpower management, safety issues, and working environment restrictions in railway vehicle maintenance work. Statistical analysis will be more accurate if the experiment is designed and performed considering these variables [50].

## IV. DISCUSSION

Maintenance staff could learn effectively when the complex pneumatic flow of BOU is implemented using a particle system of Unity. This method can be a systematic and effective way in the field of railway vehicle maintenance, where the importance of education is emerging.

The SLMVC algorithm uses two variables (e.g., object transform position, animation duration). According to these values, distance and duration per distance ratio are automatically calculated, and each particle object is displayed simultaneously in 2D and 3D coordinate systems.

The CEPC algorithm uses the following 4 variables among the 24 properties of the particle system (e.g., start lifetime, start speed, emission rate over time, start delay). When each property is inputted, it is automatically corrected, Dot-shaped particles are continuously emitted and displayed as streamlines by innumerable overlaps. Using these two algorithms reduces work time, prevents incorrect input, and increases the stability of animation output. Additionally, the pneumatic flow of BOU is displayed on one screen as two streamlines matched to each other in the 2D schematic and 3D model, respectively. This provides a learning environment for users to compare the two flow simultaneously. These algorithms can be used to implement not only BOU but also all flows of electrical and mechanical devices invisible to the naked eye.

To verify the usability of the content, the experiment was conducted by dividing into two groups, and the results were comparative analyzed. The experiment was designed to learn the hierarchy and pneumatic flow of BOU with different education methods for each group and complete the evaluation sheet and NASA-TLX survey. As a result of comparative analysis of experiment data by group, the difference in mean completion time was not statistical significance because the p-value of the T-test was greater than the significance level (0.05). However, the p-value of T-test in 3 parts (e.g., component name, pneumatic flow, NASA-TLX) was lesser than the significance level (0.05), the mean score difference of each group was statistically significant.

These results demonstrated that the use of AR content is effective in learning the essential competencies needed for BOU maintenance and reduces the perceived workload of maintenance staff.

## V. CONCLUSION

In this study, AR content was designed for maintenance staff to effectively train pneumatic flow of railway vehicle BOU. This content displays the pneumatic flow as streamlines matched to each other in a 2D circuit diagram and a 3D model by using SLMVC and CEPC algorithms. To verify the usability of the developed content, an experiment was conducted by dividing into group A using the existing booklet-type manual and group B using AR content. The conclusions obtained through the study are as follows:

1) The pneumatic flow was simultaneously displayed in a 2D pneumatic circuit diagram and a 3D model using the SLMVC algorithm. As a result, it was possible to match the two pneumatic flows with each other and it showed a 62% reduction in the performance part score of NASA-TLX.
2) Dot-shaped particles are continuously emitted and could display pneumatic flow as streamlines by using the CEPC algorithm. As a result, it was possible to intuitively learn the pneumatic flow, which was difficult to identify with the naked eye and it showed a 64% reduction in the frustration part score of NASA-TLX.
3) As a result of the experiment for the NASA-TLX survey, the difference in mean completion time was insignificant. However, the mean number of correct answers increased by 68% in group B, and the perceived workload decreased by 28% in group B.
4) Except for these, because AR content was designed based on MAR in consideration of the environment of railway vehicle maintenance work, it is convenient to utilize and not limited by time and space.

In conclusion, The developed content in this study is a practical system that could overcome the shortcomings of the existing education method and increase the efficiency of job training. If railway operating organizations use AR content as educational materials for new employees or job transitioners, it will revolutionize maintenance education.

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