# Enhancing Ramp Safety at Tan Son Nhat Airport Through Virtual Reality-Based Training

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## ABSTRACT

*Purpose* – This research explores the use of Virtual Reality (VR) technology as a sustainable and effective alternative to traditional ramp safety training methods in aviation.
*Research methodology* – The study is conceptual in nature and based on an analytical review of current practices, emerging VR technologies, and their applications in aviation safety training. It evaluates the benefits and implications of VR through scenario-based simulations and case insights.
*Findings* – VR allows aviation personnel to engage in realistic ramp safety simulations without exposure to actual hazards. It enhances training quality by enabling immersive and repeatable practice in high-risk scenarios. VR-based methods reduce the need for physical presence on the apron, thereby minimizing environmental impact and operational disruptions. The training process becomes more time-efficient and resource-conscious.
*Research limitations* – As a conceptual study, this paper does not include empirical data from field trials or quantitative performance metrics. Further research is required to validate VR effectiveness through real-world implementation and user feedback.
*Practical implications* – Implementing VR in ramp safety training can:

- Improve safety outcomes for ground personnel.
- Decrease training costs and time.
- Support environmental sustainability by reducing apron access needs.
- Align with industry trends toward digitalization and eco-friendly operations.

**KEYWORDS**: Ramp safety, Virtual reality, Immersive environment, Aviation training, Tan Son Nhat Airport.

## 1. Introduction

The International Civil Aviation Organization (ICAO) emphasizes the importance of safety management across all aviation activities, including ground operations.
Safety in aviation is the discipline focused on minimizing risks and preventing accidents in the air transport industry. It involves a comprehensive system of regulations, procedures, technologies, and human factors designed to ensure the safety of passengers, crew, and aircraft. The International Civil Aviation Organization (ICAO) sets global standards and recommended practices for aviation safety, while national Civil Aviation Authorities (e.g., FAA, EASA, CAAV) are responsible for implementing and enforcing these regulations. These standards and regulations cover airworthiness, operational procedures, maintenance requirements, and safety management systems (SMS).

At Vietnam Aviation Academy (VAA), safety is of paramount importance as it ensures the well-being of passengers, crew, and aircraft, while also maintaining public confidence in the aviation industry. Given the complex and high-risk nature of aeronautical operations, even minor errors can lead to severe consequences. Therefore, a strong safety culture is essential to minimize risks and prevent accidents. This is why VAA places a significant emphasis on safety training, equipping students and aviation professionals with the knowledge and skills needed to adhere to international safety standards and best practices. By focusing on comprehensive safety training, VAA not only enhances the operational safety of future aviation professionals but also contributes to the overall advancement and reliability of the aviation industry.

Virtual Reality (VR) has recently been established as a significant training modality, providing immersive and interactive simulations of real-world environments (Ribeiro et al., 2021); (Lewczuk & Żuchowicz, 2024). This technology facilitates the acquisition of practical skills within a secure, regulated setting, thereby mitigating the hazards inherent in conventional on-site training. The application of VR substantially improves situational awareness, decision-making processes, and emergency response proficiencies, all of which are essential for personnel operating in airport environments and ground safety protocols.

Virtual reality (VR) training offers distinct advantages for learning and skill development, with research highlighting its impact on memory and engagement. A study by Krokos et al., 2019 found that participants using an immersive VR "memory palace" experienced an 8.8% improvement in recall compared to those on a traditional desktop version, suggesting that the immersive nature of VR can significantly enhance memory and learning.

Building on these benefits, a comprehensive report by PcW, 2022 identifies several advantages of VR training over traditional methods. These include reduced training costs by minimizing the need for expensive equipment or travel, and enhanced safety by allowing participants to practice dangerous scenarios without real-world risk. The report also notes that active engagement with the training content in VR leads to improved knowledge retention and that learners in VR could be trained up to four times faster than in a conventional classroom setting.

Furthermore, the immersive qualities of VR are instrumental in developing practical capabilities. The technology has been shown to enhance a learner's cognition and their ability to acquire new technical and psychomotor skills, reinforcing its role as a powerful training tool (Radianti et al., 2020).

In alignment with contemporary trends toward digitalization and sustainability within the aviation and training sectors (Business Airport International, 2020; IATA, 2019), the Vietnam Aviation Academy (VAA) is implementing VR into its safety training curricula. This integration enables trainees to interact with high-fidelity scenarios and practice emergency protocols without exposure to actual risks. Beyond pilot training, VR is also being effectively utilized for aircraft maintenance and cabin crew training, allowing technicians to practice complex procedures and cabin crew to simulate emergency evacuations in a safe environment (Ainakulov et al., 2022; Eschen et al., 2018; Neretin et al., 2021). Consequently, VR technology represents an advanced and environmentally conscious substitute for traditional training methodologies. This initiative by VAA seeks to elevate the readiness of prospective aviation professionals while simultaneously advancing technological development and environmental stewardship within the industry.

While the benefits of VR in aviation training are compelling, it is important to address challenges such as cybersickness and ensuring that VR systems can fully replicate the tactile feedback of real controls. Ongoing research and development are focusing on refining VR technology and training design to overcome these limitations and ensure widespread adoption (Skies Mag, n.d.; Finnair France, n.d.).

## 2. Ramp safety state of art

The air transport industry is a crucial driver of global economic activity and development. To sustain the vitality of civil aviation, it is essential to ensure operations that are safe, secure, efficient, and environmentally sustainable at the global, regional, and national levels.

### *2.1 Aviation's Post-Pandemic Recovery and Its Impact on Airports*

In recent years, the global aviation industry has experienced continuous growth and is showing strong signs of recovery following the pandemic. The number of global air passengers continued to increase in 2023, with approximately 4.2 billion passengers transported worldwide, up from 3.2 billion passengers in 2022. Although still slightly below the pre-pandemic level in 2019, when 4.5 billion passengers were transported globally, the passenger volume in 2023 represents a 30% increase compared to 2022 ().

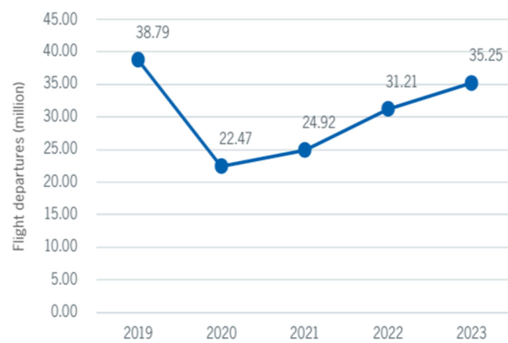


**Figure 1:** Global passenger traffic from 2019 to 2023

*Source: ICAO Safety Report 2024*

The number of scheduled commercial flight departures also continued to grow by approximately 13%, with over 35 million flights departing in 2023, compared to around 31 million flights in 2022 (Figure 1) (International Civil Aviation Organization, 2024).


**Figure 2:** Report of the Airports Corporation of Vietnam (ACV) in 2024

*Source: ACV*

Vietnam's aviation sector has mirrored this growth, with passenger volume reaching 113.5 million in 2023 and a forecast of 109 million for 2024 (Figure 2) (Airports Coparation of Vietnam, 2024). This rapid increase in traffic places significant strain on airport infrastructure and ground handling services, directly impacting ramp safety.

### *2.2 ICAO Safety report*

The 2024 ICAO Safety Report (International Civil Aviation Organization, 2024) indicates that the year 2023 marked the safest period for global aviation within the preceding five years. A global accident rate of 1.87 accidents per million flight departures was recorded, representing a 50% reduction in fatalities compared to 2022. This improvement occurred despite a 13% increase in flight departures, resulting in a 17.9% decrease in the overall accident rate. Only one fatal accident was reported, attributed to Loss of Control In-Flight (LOC-I), which accounted for all 72 fatalities.

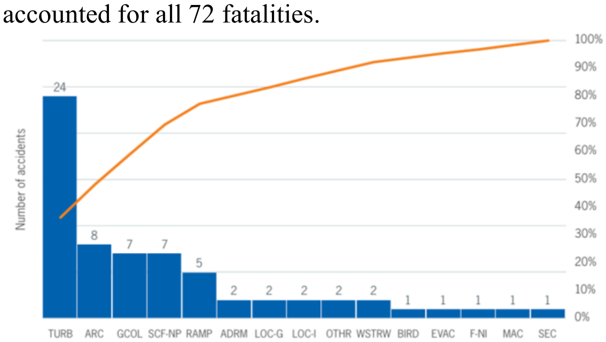


**Figure 3:** Total accidents by occurrence category in 2023
*Source: ICAO 2024*

As illustrated in **Figure 3**, the report identifies turbulence encounters (TURB) and abnormal runway contact (ARC) as the most prevalent accident categories, collectively contributing approximately 50% of all reported occurrences. Additionally, Ground Collision (GCOL) and Ground Handling (RAMP) incidents were significant contributors to accidents, primarily resulting in substantial aircraft damage without associated fatalities. The sole fatal accident in 2023 occurred within the Asia and Pacific (APAC) region, while other regions reported accidents leading to substantial aircraft damage or serious injuries but no fatalities. **Figure 4** further details the incidence of aircraft damages in 2023, clearly demonstrating that GCOL and RAMP incidents were the primary causes. This underscores the critical need for enhanced safety protocols and procedures within ground operations.

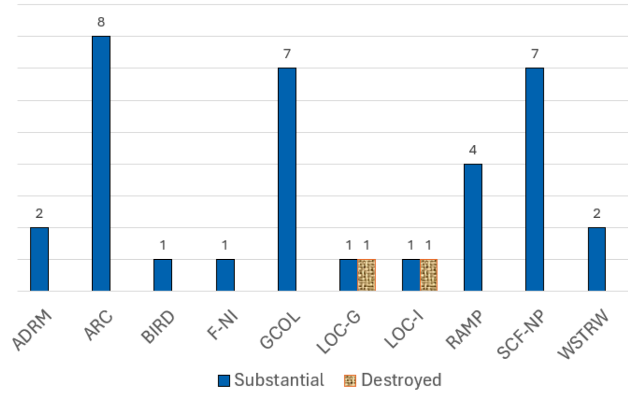


**Figure 4:** Aircraft damage by occurrence category in 2023
*Source: ICAO 2024*

### *2.3 Tan Son Nhat International Airport safety report*

Tan Son Nhat International Airport (TIA) in Ho Chi Minh City functions as Vietnam's primary and largest aviation hub. In both 2023 and 2024, TIA processed 40.7 million and 39.9 million passengers, respectively. These figures substantially exceed its designed annual capacity of 28 million passengers, leading to considerable congestion on the apron and taxiways. To alleviate this, an expansion project, involving the construction of Terminal 3, commenced in December 2022, with an anticipated completion by April 2025. Despite these efforts, ramp safety remains a critical concern, particularly during peak travel periods such as the Lunar New Year (Tet Holiday) and other festivals, due to persistent overcrowding and overcapacity. The high volume of flight operations places significant strain on ground handling services, thereby escalating the risk of ground collisions (GCOL), equipment-related accidents, and occupational hazards for ground personnel.

In 2024, TIA reported 115 safety incident related to aircraft in (Tan Son Nhat Internation Airport, 2024) and the 2024 safety target was not achieved.

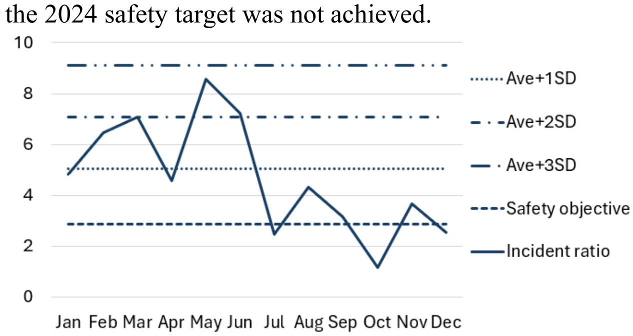


**Figure 5:** Incident ratio concerning aircraft at TIA in 2024
*source: ACV Tan Son Nhat*

Figure 6 illustrates the incident ratio concerning aircraft at TIA in 2024. The primary factor contributing to the failure to meet the 2024 aircraft incident target was aircraft taxiing beyond the designated stop line at aircraft stands, accounting for 61 cases, or 53% of all incidents.

Other significant contributing factors included obstacle clearance safety (27 cases, 23.5%), vehicles/equipment violating aircraft safety distances (9 cases, 7.8%), and vehicles/equipment colliding with aircraft (8 cases, 7%). To mitigate these identified safety risks, continuous infrastructure development and the implementation of efficient ground management practices are imperative. This necessitates the adoption of advanced safety protocols and comprehensive training for ground staff to ensure the maintenance of safe and efficient airport operation.

## 3. VR development engine and process

### *3.1 VR development engine*

Currently, VR and AR applications are primarily developed using two popular platforms: Unity (Unity Technologies, 2022)and Unreal Engine (Epic Games, 2022). Both are powerful tools for programming and managing 3D environments and objects, making them the go-to choices for most modern games, 3D applications, virtual reality, and augmented reality software.

Unity 3D Engine is well-suited for both 2D and 3D game development and supports multi-platform environments such as Windows, iOS, and Android, using popular programming languages. On the other hand, Unreal Engine is favored by many developers for its cross-platform compatibility, user-friendly features, and support for commonly used programming languages.

The choice between Unreal and Unity for VR programming depends on the specific requirements, scenarios, and product characteristics (Akhil, 2023). After analyzing the high resolution and realism requirements of the application, the research team chose Unreal Engine as the development tool for this project.

**Table 1:** Unity and Unreal Engine comparison

| | Unity | Unreal |
|---|---|---|
| Graphics | Physically-Based Rendering, Global Illumination, Volumetric lights after a plugin installed, Post Processing | Physically-Based Rendering Global Illumination, Volumetric lights out of the box, Post Processing, Material Editor, Dynamic lighting |
| Unique Features | Rich 2D support | AI, Network Support |
| Target Audience | Mostly indies, coders | AAA-game studios, indies, artists |
| Coding | C#, Prefab, Bolt | C++, Blueprints |
| Community | More than 200k members | About 100k members |

### *3.2 A structured development framework*

The development of a VR simulator for airport operation training and ramp safety training involves several structured phases to ensure an effective and realistic learning experience. The procedure can be broken down into the following steps (Lewczuk & Żuchowicz, 2024)

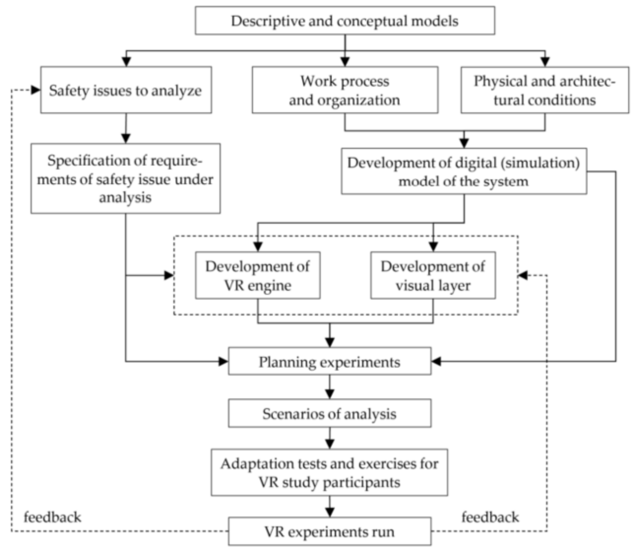


**Figure 7:** Simplified scheme for designing a simulation model for VR experiments

*Source*: *Lewczuk & Żuchowicz, 2024*

The next section will provide a detailed overview of the system architecture, along with the 3D model construction process and the final model utilized in the simulator.

### *3.3 Apron safety simulator development*

#### 3.3.1 System architecture

The apron safety simulator includes main component: Simulator software running on a computer, Oculus Quest 2 and Logitech G29 as shown in Figure 8**Error! Reference source not found.**. In this section, the application development will be discussed in detail.

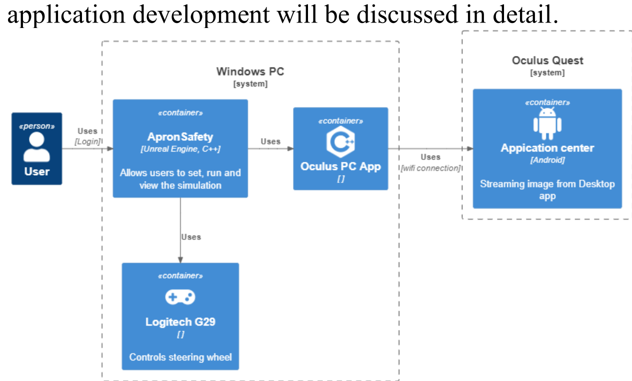


**Figure 8:** ApronSafety simulator system diagram.

*Source: authors'*

In order to train all safety-related activities on the apron, the application is designed to include the following user groups: aircraft maintenance personnel, aircraft marshallers, ground support equipment operators, and other personnel who frequently operate on the apron. In the initial phase of development, the research team focuses on bus drivers and aircraft marshallers, as these two groups have the most significant impact on ramp safety at Tan Son Nhat Airport.

### 3.3.2 Airport 3D model construction

Process-built virtual reality applications include three main steps: modelling, painting and materials, and virtual reality programming. The construction of models will be done in 2 steps: modelling and painting, materials. First, virtual models are modelled using 3D modelling tools to create 3D geometry of the object. After completing the 3D modelling process, the models are rendered using computer graphics techniques including material painting, texture mapping, and more. This process can be done directly on 3D modelling. In this procedure, Maya and Photoshop are used to construct the 3D models and textures rescpectively.

To develop a graphical model of the apron and airfield, comprehensive data, diagrams, maps, and statistical information pertaining to the airport's layout were collected from the most recent master plan as shown in Figure 9.

**Figure 9:** Master Plan of Tan Son Nhat International Airport

*Source: ACV Tan Son Nhat*

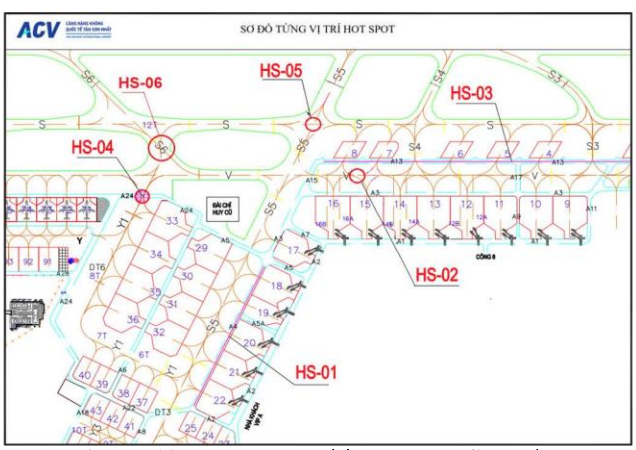


**Figure 10:** Hot spot position on Tan Son Nhat International Airport

*Source: ACV Tan Son Nhat*

In addition, Tan Son Nhat International Airport has also identified and published areas where frequent incidents of ground vehicle/equipment collisions with aircraft or violations of aircraft taxiing safety distances occur (hot spot). This is done to ensure aircraft safety during operations and to raise awareness among drivers and operators of ground service vehicles and aviation equipment operating within the airport's restricted areas. The goal is to remind personnel to exercise caution while operating vehicles and equipment, thereby minimizing the risk of collisions. 6 hot pots of TIA are shown in Figure 10.

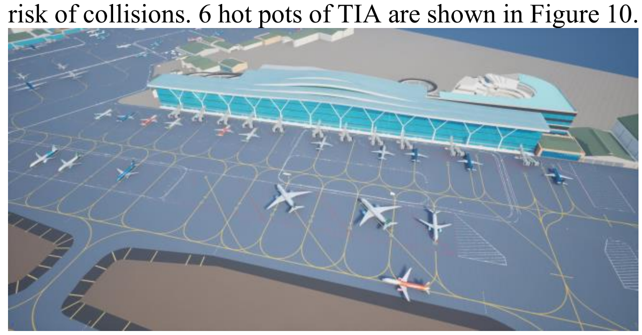

**Figure 11:** TIA's apron 3D model

*Source: authors'*

A high-precision 3D apron model is to be developed to realistically replicate the actual working environment at the airport. The model must ensure realism, technical accuracy, and a high level of interactivity, while being optimized for performance within a Virtual Reality (VR) environment. The 3D model will include several key components: **(1) Apron surface**—realistically simulating dimensions, textures, and surface patterns, including clearly marked stop lines, guidance lines, restricted zones, and aircraft parking positions. The surface will feature reflections, shadows, stains, oil spills, and tire marks to enhance realism; **(2) Service roads**—fully modeled with route layouts, speed limit signs, lane markings, and internal traffic signs. The system may incorporate speed-limit detection for assessing trainee behavior (e.g., point deductions for speeding); **(3) Taxiways**—adjacent taxiways will be rendered with the ability to simulate aircraft interactions, including scenarios such as stopping correctly at hold lines when aircraft are crossing; **(4) Aircraft parking positions (Bay/Gate)**—each bay will be detailed with lighting systems, gate numbers, GPU connectors, signal markings, and designated marshaller standing positions. Additionally, the newly constructed Terminal T3 is integrated into the TIA 3D model (**Figure 11**) to reflect the airport's latest developments and ensure up-to-date simulation training.

### 3.2.3 Aircraft and vehicle 3D model construction

The first 3D model in present research is Airbus A320 which is the most popular aircraft in Vietnam's civil aviation. Based on the aircraft's parameters in Airbus document (Airbus, 2005), the research team built a 3D model for the aircraft and conducted meshing. In order to simplify the construction of the A320 model, the aircraft is divided into separate parts. The fuselage and wings were first built and shown in Figure 12. On the fuselage, the positions of doors, windows, cockpit windows, and wing installation positions are pre-set as. Due to small parts such as windows, aircraft main doors, the total number of UV filter elements increases significantly. The entire fuselage is divided into 64236 mesh elements and other parts contain 218996 triangle mesh. The completed model of A320 with texture is shown in Figure 12**Error! Reference source not found.**.

**Figure 12:** UV mesh on aircraft's body and wings

*Source: authors'*

Passenger buses at Tan Son Nhat Airport come in various types. The research team selected the Cobus 3000 for the driving simulation application. Cobus is a specialized bus designed specifically for airport passenger transportation, with a capacity of up to 112 passengers. It is designed to optimize passenger flow during boarding and deboarding in the shortest time possible while ensuring maximum comfort. **Figure 13** shows the basic dimensions of the Cobus 3000 bus.

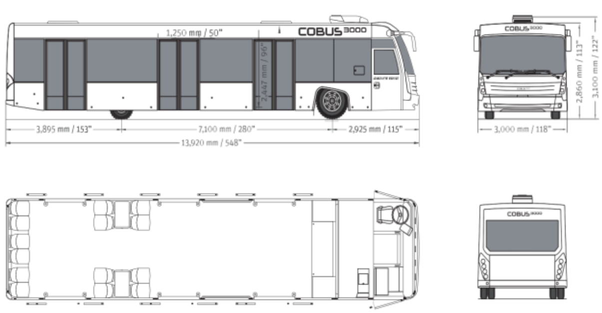


**Figure 13:** The basic dimensions of the Cobus 3000

*Source: authors'*

The model built based on the above dimensions was UV-mapped with a total of 14,486 mesh elements, illustrated in **Figure 14**. Additionally, the bus includes several auxiliary components such as wheels, driver's seat, doors, and others, which were also modeled and meshed. After getting the UV mesh, the texture will be added to get the final model.

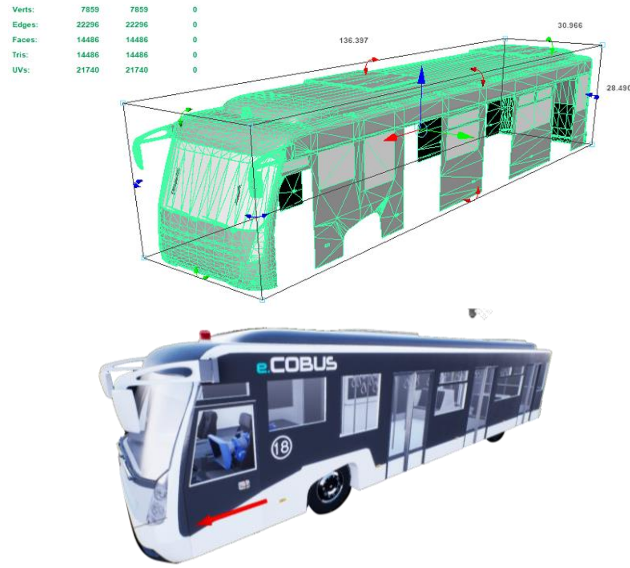


**Figure 14:** 3D model and UV mesh on the bus body

*Source: authors'*

After the bus model is imported into UE5, a new object is created for interactive programming purposes. This object manages the model and logical functions of the bus. **Figure 15** shows the bus object and its workstation screen in Unreal Engine. This object includes the vehicle body, cockpit, interactive components in the cockpit, wheels, lights, and other material properties.

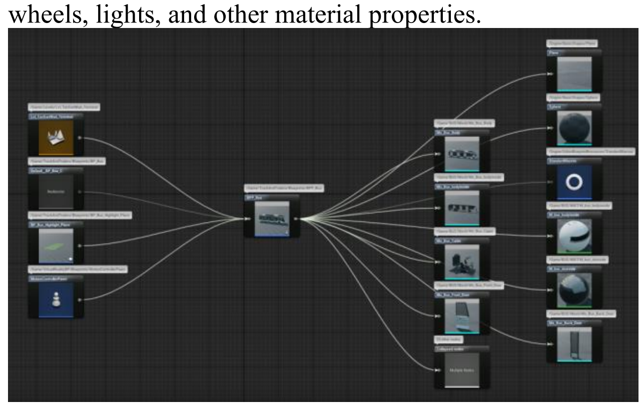

**Figure 15**: Bus object linked with other objects on Blueprint

*Source: authors'*

## 4. VR simulation

The simulator includes several training modules designed to target the specific safety issues identified at TIA.

### *4.1 Bus Driving Practice*

This module focuses on the skills required for safe bus operation on the apron. The skills covered in this practice include (Ministry of Transport, 2016):

- Driving the bus along a designated route;
- Maintaining the bus speed according to regulations;
    - 05 km/h in the aircraft parking safety zone.
    - 35 km/h on the airside service roads.
- Avoiding collisions during the approach process;
- The practice session ends when the vehicle stops at the designated position.

The simulation path is shown in **Figure 16**. Along the bus's movement path, regulatory and safety conditions will be activated and monitored to supervise and assess the trainees.

**Figure 16**: Diagram of bus driving practice

*Source: authors'*

After taking the driving position. On this screen, the driver can view the movement path and the pre-set directional arrows guiding the route, as shown in Figure 17.

**Figure 17:** Driving practice at VAA

*Source: authors'*

After the trainee completes the journey, a result summary will be generated and displayed on the screen, allowing the trainee to evaluate their performance as shown in Figure 18.


**Figure 18:** Simulation report

*Source: authors'*

### *4.2 Aircraft marshalling*

This module addresses the most frequent type of incident at TIA: issues related to aircraft taxiing and marshaller-pilot cooperation. The simulation covers 29 actions to guide the aircraft into gate, in accordance with ICAO regulations and detailed by ACV's internal training procedures (Vietnam Air Traffic Management Corporation, 2024). All these activities will be simulated in marshalling module. **Figure 19** presents the simulation scenario for marshalling. This scenario includes 10 steps with 2 two concerning the high-risk event beside the normal activities of the marshalling procedure.

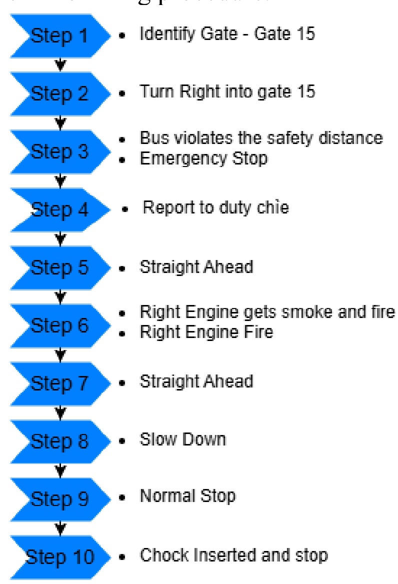


**Figure 19:** Marshalling scenario

*Source: authors'*


**Figure 20:** Marshalling selection in ApronSafety simulator *source: authors'*

In addition to the primary scenario, the weather conditions can be dynamically altered to include a variety of settings, such as sunny, rainy, foggy, and clear night conditions. This range of weather options is designed to enhance the training experience by simulating different environments, allowing for more comprehensive performance testing and skill development in a variety of conditions.


**Figure 21:** Marshalling tutorial at gate 15

*Source: authors'*

After finishing the marshalling, trainee will be reported about the procedure and mistakes that happened during the session.

### *4.3 Aircraft walkaround inspection*

The practical lesson "Pre-Flight Inspection" is designed to help trainees master the procedures for conducting a comprehensive external check of the aircraft prior to departure, ensuring operational reliability and safety. Through hands-on activities on a real aircraft or a simulation model, trainees will develop their skills in observation, assessment, and identifying abnormalities that may affect the flight. Within the scope of this module, the pre-flight inspection focuses on simulating and addressing issues related to ramp safety, including maintaining a safe distance from operating engines and identifying aircraft-related incidents that could impact ramp safety.

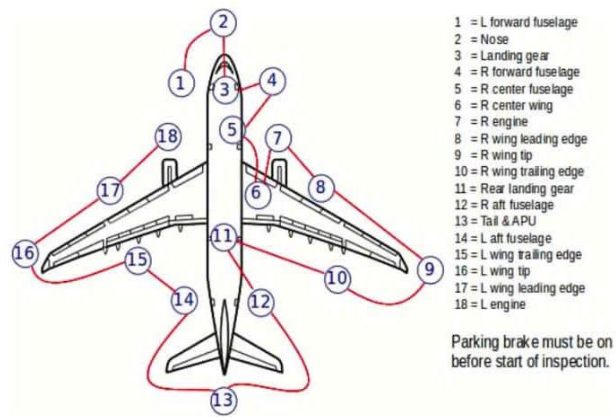


**Figure 22:** A320 walkaround procedure

*Source: Airbus*

Step 1
- Select Walkaround simulation

Step 2
- The trainee proceeds to inspection positions 1 - 6
- The trainee reviews the inspection checklist and observes the equipment displayed on the board.

Step 3
- The trainee proceeds to inspection position number 7 (engine)

Step 4
- Upon detecting a minor oil leak, the trainee may use a cloth to wipe it clean

Step 5
- Upon detecting a major oil leak, the trainee must not attempt to clean it with a cloth
- They should immediately report it to the flight crew

Step 6
- Finish

**Figure 23:** A320 walkaround scenario

*Source: authors'*

## 5. Conclusion

This paper has presented a conceptual framework for a VR-based training simulator designed to enhance ramp safety at Tan Son Nhat International Airport. By analyzing the specific incident data from TIA, we have identified critical risk areas—primarily ground vehicle operations and aircraft marshalling—and proposed a set of targeted VR training modules to address them. The detailed development process, from the selection of Unreal Engine for its high-fidelity graphics to the construction of accurate 3D models and realistic, data-driven scenarios, demonstrates the feasibility and potential of this approach.

The proposed VR simulator offers a safe, controlled, and immersive environment for personnel to practice high-risk procedures without disrupting airport operations or exposing themselves to real-world dangers. This method aligns with global trends in aviation toward digitalization and sustainability, providing a cost-effective and environmentally friendly alternative to traditional training. As a conceptual study, this work's primary limitation is the absence of empirical data from real-world implementation. Therefore, the next crucial phase of this research will be to move from concept to practice. Future work will involve:

1. **Full-Scale Development and Deployment:** Completing the development of all proposed training modules and deploying the simulator at the Vietnam Aviation Academy.
2. **Empirical Validation:** Conducting controlled trials with student groups to validate the effectiveness of the VR training. Key performance indicators will include knowledge retention, skill acquisition speed, and decision-making accuracy in simulated emergencies.
3. **User Feedback and Iterative Improvement:** Gathering qualitative feedback from trainees and experienced ground personnel to refine the scenarios, enhance user experience, and address limitations such as the lack of tactile feedback.
4. **Long-Term Impact Assessment:** Collaborating with Tan Son Nhat International Airport to track ramp incident statistics following the integration of VR-trained personnel, aiming to measure the simulator's long-term impact on operational safety.

By systematically validating and refining this technology, we can build a powerful tool that not only improves safety at Tan Son Nhat but also serves as a model for other airports facing similar challenges of congestion and operational risk.

## Acknowledgments

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