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Edurail: Railway Simulation Using Virtual Reality Technology

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Abstract

Virtual reality is new, advanced technology that has created digital environments that allow users to interact with virtual scenarios in the most realistic and intuitive manner. In railway education and similar fields, several related VR applications are useful. Some of the simulation programs are really trying to improve learning with a better sense of interaction, but some simulators are more game-oriented than educationally oriented. Some do not adequately transfer the knowledge and skills during the training process. In addition, railway training in Malaysia is still conducted within a classroom setting, which creates the gulf between theory and practice, undermining the preparedness of the students for real life situations and possibly leading to dangerous situations in railway operations. EduRail: Railway Simulation is proposed to solve these problems. EduRail utilizes VR technology in bridging theory-based learning to practical training through the real immersion of students into the operation of trains, station environments, and emergency scenarios. EduRail is designed per the TRES-D methodology; thus, it offers dynamism and interactivity during learning, with framing targeted to meet university needs and professional licensed training. The target user for the application are students studying railway related field. In this case, the Faculty of Engineering Technology Students that are currently studying in Universiti Tun Hussein Onn Malaysia (UTHM). The results of user acceptance of this application were evaluated using the System Usability Scale (SUS) method which showed an excellent average score of 84.41.

1. Introduction

The railway system in Malaysia is an integral part of the transportation structure of the nation, which links cities, supports economic activities, and carries thousands of passengers every day. The expansion of Malaysia's rail network into more advanced systems such as the Electric Train Service (ETS) and Diesel Multiple Unit (DMU) further underlines the demand for skilled professionals who are capable of operating and managing such complex systems [1].

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While there is this demand, it has not been easy equipping the future professionals with the necessary skills. Universiti Tun Hussein Onn Malaysia's Faculty of Engineering Technology, or UTHM, runs a course to help students grasp the theoretical perspective in relation to the growing railway network within Malaysia [2]. However, most of these traditional classroom teaching approaches are often informative but leave students very ill-prepared for on-site and real-time situations that arise in railway operations. Most of the conceptual learning focuses on lecture-based approaches, textbook learning that does not develop hands-on skills or experience for railway industrial purposes [3].

This is where virtual reality technologies have come in is to change this landscape of opportunity. With virtual reality, the creation of an immersive and interactive environment lets students experience a realistic scenario that cannot be replicated through traditional teaching methodologies. As pertains to railway education, VR presents a special way to bridge the gap between theoretical knowledge and practical application-challenges that are usually experienced from conventional approaches to learning and training [4].

It is here that EduRail—a Virtual Reality-based train simulator—offers an innovative solution to bridge this gap for UTHM students. EduRail enables the replication of real-life railway conditions that are not achievable by other means. It shall allow students to rehearse all critical tasks, such as operating trains, managing stations, or practicing safety protocols, without associated on-job risks and costs. EduRail provides the student with the opportunity to develop core competencies in hazard recognition, emergency response, and decision-making under pressure through repeated exposure to realistic scenarios, all with immediate feedback.

2. Related Work

This section discusses the background of the study, gameplay used, and the result of the comparative analysis

2.1 Train Simulation

Train simulation is a very specialized area that usually deals with the use of software or mechanical systems to simulate the operational dynamics of trains and railway networks. In professional settings-actual railway companies or schools for train operators-the usage of simulators is extensive. These systems enable operators to experience realistic scenarios without the risks associated with handling real trains. Trainers would replicate variables such as extreme weather conditions, systems failure, and even emergency scenarios to make sure that operators are prepared for all manner of situations. This is also one way of improving safety and efficiency, thereby minimizing or even totally averting any accidents or mishaps during the actual operation of trains. For instance, the use of simulators in the European Rail.Traffic Management System (ERTMS) ensures that train operators can be trained on new signaling systems without interrupting real-world services [2]

2.2 Virtual Reality

Virtual reality is a disruptive technology that plunges users into artificially produced environments with which they can interact in manners that simulate either real-life or completely imaginary situations. Most of the time, it requires a headset that sends and receives information related to the movement of the head and body to give a 360-degree point of view. Entertainments, games, medical training, engineering design, and remote collaboration are all parts of applications of VR. For example, in education, it finds its place in creating virtual labs that allow students to perform experiments in a mock environment, thus enhancing learning and reducing costs and risks of actual physical setup. [8].

2.3 Comparative Analysis

Existing applications have their own strengths and weaknesses. Based on the comparison of the applications made, the advantages and disadvantages of the existing applications can be considered for incorporation into the Edurail: Railway Simulation application that is being developed to achieve optimal results. Table 1 below shows a comparison between the Edurail: Railway Simulation application and several selected existing applications. Among the aspects compared are the supported platforms, technologies used, operating systems, languages, price , and pros.

Table 1 Comparison table between existing applications with the proposed application

Application Features	Train Sim World[11]	Simrail : The Railway Simulator[12]	Derail Valley[13]	EduRail : Train Simulation
Supported Platform	Steam.	Steam	Steam	Meta Quest Vr
Technology	Game	Game	Game	Virtual Reality
Operating System	Windows, Linux	Windows, Linux	Windows	Windows, Meta Quest
Language	English	English	English	English
Price	Paid	Paid	Paid	Free
Pros	• Extensive library of trains and route • Focus on Realism	• Multiplayer mode for cooperative play • Focus on real world scenarios and professional train operation	• Focus on train handling • Sandbox mode allowing free exploration and experiment ation	• Focused on educational training • Realistic simulation of train operations, and safety protocols • Designed for immersive, independent VR learning with 3d environment

3. Methodology

The development of the EduRail: Railway Simulation application follows the TRES-D methodology, introduced by Molina et al. [12], which offers a holistic approach to creating Virtual Reality applications. This methodology integrates insights from previous approaches through an iterative and incremental process, addressing varying complexities in development scenarios. Organized into six primary stages—requirements gathering, requirements understanding, concept design, iterative design, building and implementation, and deployment and maintenance—TRES-D provides a systematic framework for developing three-dimensional user interfaces, as illustrated in Figure1.

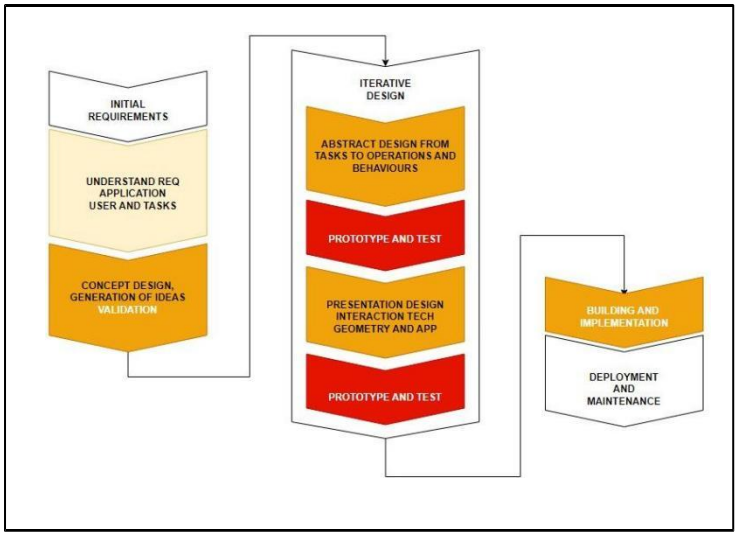

Fig. 1 *TRES-D methodology [13]*

3.1 Phase 1: Initial Requirements

This first stage identified the basic needs of the application and studied them in detail. Major elements such as the main objective, the detailed problem statement, the expected outcomes, and the overall significance of the project were discussed in great detail and clearly specified in Table 2. The establishment of these aspects provided a solid framework for the project, where all parties involved had the same understanding that is to be expected. Additionally, it was necessary to define what information and data were needed to further advance the design and development phases of the EduRail: Railway Simulation application. This included technical specifications, user requirements, and contextual insights that would guide subsequent stages. By setting out these preliminary requirements, the team ensured that the development process would be aligned with the intended purpose and objectives, minimizing the risk of scope creep and ensuring the final product met its goals effectively.

Table 2 *User Analysis*

Category of Stakeholders	Role in the Product	Design Implications	Required Actions
Subject Matter Experts (SME) Ts. Dr. Hairulazwan Bin Hashim)	Content consultants for railway-related topics	user-friendly interface	• Ensure text is clear and readable, using fonts suitable for virtual reality and university students
		Easy Navigation	• Use universal icons on buttons, such as home, settings, back, and volume, ensuring easy access for users.
		Reliable Content	• Reliable content and simple, easily understandable language means users will more likely follow through with the guide of a simulation. The content would also tally with real-life scenarios and locations.
		Multimedia Content	• Include animations, audio narrations, and interactive environment • Implement scenarios where students must choose the correct method for specific scenarios

3.2 Phase2: Understanding Requirements

In this second phase, it is essential to understand the requirements needed to develop this project. The structure of the application to be developed is analyzed in this phase. Tables 3 and 4 present the functional and non-functional requirements for the proposed application.

Table 3 *Functional requirements*

Functional Requirements	Module	Description
Autonomous system activities	Hazard and Risk Management Module	• The application shall go to the next step after the user has successfully completed the current step.

Table 3 *Functional requirements (Continued)*

Functional Requirements	Module	Description
Autonomous system activities	Comprehensive Learning Module	• The graphic of the step to conduct train and navigate step by step on how to handle scenarios when the users start encountering it • The application shall go to the next step after the condition is fulfilled by user. • Dead man's switch will trigger every 5 minute to test user reaction time • Traffic light will switch color randomly to indicate the train need to change speed
	Audio	• Background music should play when the users enter all the modules.
User interaction support	Main Interface	• The application should allow users to click on the start button tostart the application.
	Comprehensive Learning module	• Allow user to navigate into virtual environment and engage in real time • User can interact with object inside cockpit
	Hazard and risk Managemnent module	• Allow user to engage with the training module and experience virtually • Allow user to interact with hazard scene

Table 4 *non-functional requirements*

Non-functional Requirements	Description
Legal	• Users should be only able to view the content of the application but cannot modify the content.
Usability	• The application shall be user-friendly and easy to use for the users. • The user interface should be intuitive, with clear navigation cues and labels to enhance user understanding.
Operational	• The application shall be able to operate with Android version 7.1.1 "Nougat" and above.
Cultural	• The application shall be developed in English language.
Performance	• The average response time between click and reaction shall be 3 seconds. • The VR application should maintain a minimum frame rate of 60 frames per second (FPS) to ensure smooth navigation

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3.3 Phase 3: Concept Design

The Concept Design phase involves developing the initial framework for the Edurail: Railway Simulation application, including module flow, user interactions, and interface elements. Key activities were identified through interviews with Subject Matter Experts (SMEs). Unity and Blender were used for 3D modeling, while Canva was utilized for graphics. Scripts and interactivity were organized within Unity 3D to create an immersive VR experience. At the end of this phase, an initial prototype was completed as a foundation for full application development. Table 3 shows the design of the application's main buttons, while the content structure, system flow, navigation structure, and interface for each application module are detailed in Appendix A until Appendix D.

Table 5 *Button Design*

Button	Description
	● The Start button initiates the application, guiding users to the main interface to begin exploring features inside Edurail : Railway Simulator.
	● The Settings button opens the settings page, allowing users to adjust audio volume and other customizable preferences for the application.
	● The Exit button serves as a quit feature, closing the application and ending the simulation when selected
	● The Eye icon serves as an on toggle for the UI visibility, allowing users to show or hide interface elements for a cleaner or more detailed view, depending on their preference during the simulation
	● The Eye icon serves as an off toggle for the UI visibility, allowing users to show or hide interface elements for a cleaner or more detailed view, depending on their preference during the simulation.
	● The "CLICK HERE" button provides users with step-by-step guidance on operating the train, ensuring clarity and ease of understanding for smooth simulation navigation.
	● A navigation function which also act as button to indicate next objective location during hazard and risk management module and so on
	● A motion guide / button that are use to indicate the motion need to be done when starting up the engine of train

Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Table 5: *Button Design (Continued)*

Button	Description
	• The quick shortcut to Settings enables users to efficiently access the settings page without going to main menu, allowing rapid adjustments to preferences like audio and display.

3.4 Phase 4: Iterative Design

In the iteration design for EduRail : Railway Simulation, the chosen solution will undergo an in-depth design process at two levels: abstract and presentation. The iterative cycle will be performed by oscillating between two points of view until the the final design has been developed.

3.4.1 Abstract Design

This phase aims to develop a simulation framework that encompasses the workflow for each Railway Module. The concept of the virtual world has been developed with accurate placement of virtual objects and clear interactive navigation paths. The behavior of virtual elements is also identified to ensure a meaningful experience for users as they go through the simulation. For example, in some module, starting engine and dead man switch module will be replicated step by step in Virtual Reality to the extent necessary for users to follow

3.4.2 Presentation Design

In this stage, the major functions of the proposed application are developed. The major modules include two important modules: the Learning Module and the Immersive Activity Module. The Learning Module helps the users to learn how to conduct railway and a step by step guide to caution act during hazard and risk module . It will show the information of each train . In this virtual world, the C# scripting for user interaction with virtual objects is enabled to explore variety of old and new generation of trains . This learning has also been enhanced with the use of multimedia resources, such as animations showing the immersiveness and the functionality of the railway. The C# script is used to control the animation to play upon awake

3.5 Phase 5: Building and Implementation

In this stage, the major functions of the proposed application are developed. The major modules include two important modules: the Learning Module and the Immersive Activity Module. The Learning Module helps the users to learn how to conduct railway and a step by step guide to caution act during hazard and risk module . It will show the information of each train . In this virtual world, the C# scripting for user interaction with virtual objects is enabled to explore variety of old and new generation of trains . This learning has also been enhanced with the use of multimedia resources, such as animations showing the immersiveness and the functionality of the railway. The C# script is used to control the animation to play upon awake

Table 6 *3D Model Environment*

Model Name	Model Figure	Description
Main menu		Interactive Main Menu for user to use before and after using the simulation

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Table 6: *3D Model Environment (Continued)*

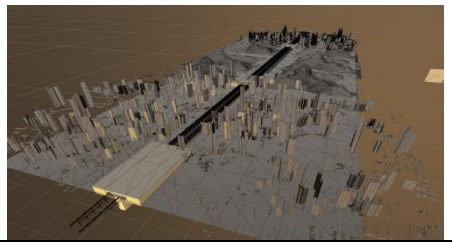
Model Name	Model Figure	Description
KTM KL Sentral		Starting station #1
Gemas Station		Starting station #2
Johor Bahru Sentral		Starting station #3
Emergency Module Area		Emergency Area
Simulation Map		Interactive map that will change according to starting station

Table 7 outlines the development of various assets and environment for the application, ensuring a rich and immersive experience. The assets enhance the quality and visual of the application. Interactive interface and environment provide users with engaging and realistic VR experience.

Table 7 *Functionality Testing*

Test	Expected Result	Actual Result
Start button	Navigate the menu panel	Works well as expected
Tutorial button	Navigate to tutorial page	Works well as expected
Setting button	Navigate to Setting page	Works well as expected
Learning Module button	To select Learning module	Works well as expected
Emergency Module button	To Select Emergency module	Works well as expected
ETS select button	Select ETS model	Works well as expected

Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Table 7: *Functionality Testing (Continued)*

Test	Expected Result	Actual Result
Gemas Station select button	Choose Gemas Station as starting scene	Works well as expected
JB Station select button	Choose JB Station as starting scene	Works well as expected
Start Simulation button	Start simulation according to selection	Works well as expected
Start Operation button	Start train operation	Works well as expected
Back button	Navigate to previous page	Works well as expected
Exit button	To exit the train and back to station	Works well as expected
Next button	Navigate to next panel	Works well as expected
BGM Slider	Slider to adjust BGM	BGM also mute button sound. Breaking the immersion of application
DMS button trigger	Turn off alarm during train operation	Works well as expected
Power lever	Lever to adjust acceleration power	Rate of acceleration is too fast and does not simulate train acceleration
Brake lever	Lever to adjust brake power	Brake power often override power lever and cause instant stop when on highest brake power
Home button	Navigate to main menu	Works well as expected
KTM Class 25 select button	Select KTM class 25 model	Works well as expected
KTM KL Station select button	Choose KTM KL Station as starting scene	Works well as expected

3.6 Phase 6: Deployment and Maintenance

The deployment and maintenance of Edurail: Railway Simulation involve continuous tuning and maintenance to keep the application at an optimum level of performance and satisfaction for its end-users. The TRES-D methodology gives room for flexibility in the deployment of updates, addressing challenges, and maintaining the immersive and educational qualities of the application. During functional testing, the buttons and features of the completed application are tested. If issues or enhancements are found during testing, the project will go back to the update of the integrated functionalities step in order to address the bugs and update the application. Once the issues are fixed and the application is stable, it will be tested on the target user for user approval

4. Result and Discussion

Overall, this project has been successful in achieving 100% of its three main goals, namely: developing Edurail : Railway Simulation Using Virtual Reality Technology as a user friendly and visually immersive, developing the application on the Android operating system using unity software and Virtual Reality (VR) technology, lastly, testing the user acceptance of the application on 15 respondents. Statistical results on the respondents are illustrated in Figure 2 and Figure 3 below.

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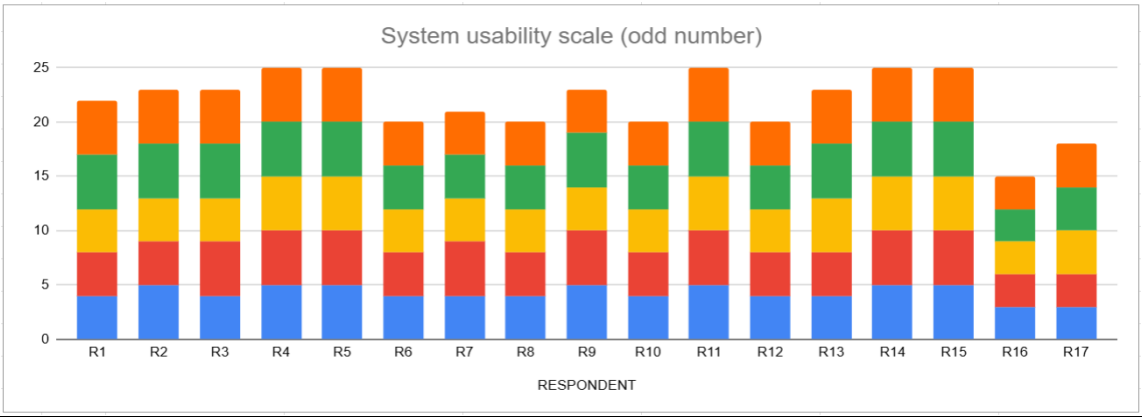
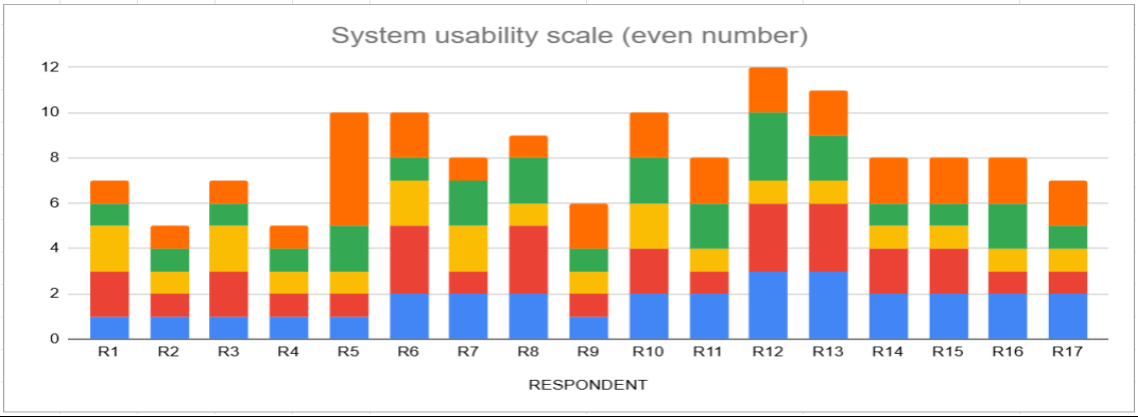


Question 1	I think I would like to use this system frequently
Question 2	I though the system was easy to use
Question 3	I found the various functions in this system were well intergrated
Question 4	I would like to imagine the most people would learn to use this system very quickly
Question 5	I felt very confident using the system

Fig. 2 *System Usability Score (odd number)*

Figure 3 shows that the majority of respondents giving lower scores (1,2 and 3) compared to Figure 2 for event-numbered questions, indicating disagreement with negative statements and therefore expressing a positive attitude towards the usability of the application. However, some resondent did have trouble playing with the application on their own.Therefore, initial use and support guidance is recommended in order to obtain the best overall system usability.



Question 1	I found the system unnecessarily complex
Question 2	I think that I would need the support of a technical person to be able to use this system
Question 3	I thought there was too much inconsistency in this system
Question 4	I found the system very cumbersome to use
Question 5	I needed to learn a lot of things before I could get going with this system

Fig. 3 *System Usability Score (even number)*

The result from Figure 2 and Figure 3 from above are summarised in Table 8. Table 8 shows the average usability score of Edurail: Railway Simulation application based on the scale selected by 17 respondents. The average usability score are shown in formula below.

Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Total Score = (Total Odd + Total Even) x 2.5
Average Score = Total Score / Total Respondent

Where :
Total Odd = (Q1,Q3,Q5,Q7,Q9) = Total-1
Total Even = (Q2,Q4,Q6,Q8,Q10) = 5-Total

Table 8 *Respondent's score*

RESPONDENT	Item Score										Total Odd	Total Even	Total Score
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10			
R1	4	1	4	2	4	2	5	1	5	1	18	17	87.5
R2	5	1	4	1	4	1	5	1	5	1	20	18	95
R3	4	1	5	2	4	2	5	1	5	1	18	18	90
R4	5	1	5	1	5	1	5	1	5	1	20	20	100
R5	5	1	5	1	5	1	5	2	5	5	15	20	87.5
R6	4	2	4	3	4	2	4	1	4	2	15	15	75
R7	4	2	5	1	4	2	4	2	4	1	17	16	82.5
R8	4	2	4	3	4	1	4	2	4	1	16	15	77.5
R9	5	1	5	1	4	1	5	1	4	2	19	18	92.5
R10	4	2	4	2	4	2	4	2	4	2	15	15	75
R11	5	2	5	1	5	1	5	2	5	2	17	20	92.5
R12	4	3	4	3	4	1	4	3	4	2	13	15	70
R13	4	3	4	3	5	1	5	2	5	2	14	18	80
R14	5	2	5	2	5	1	5	1	5	2	17	20	92.5
R15	5	2	5	2	5	1	5	1	5	2	17	20	92.5
R16	3	2	3	1	3	1	3	2	3	2	17	10	67.5
R17	3	2	3	1	4	1	4	1	4	2	18	13	77.5
Average Score													84.41

Based on the results analyzed from testing phase, The Edurail Railway Simulation application is suitable for the target user to increase their understanding of Railway and how to operate them. As shown in Figure 4, the average score that is 84.41 shows that the system achieved Excellent acceptability range. This shows that Edurail Railway Simulation contain high functionality and achieved the objective of the project.

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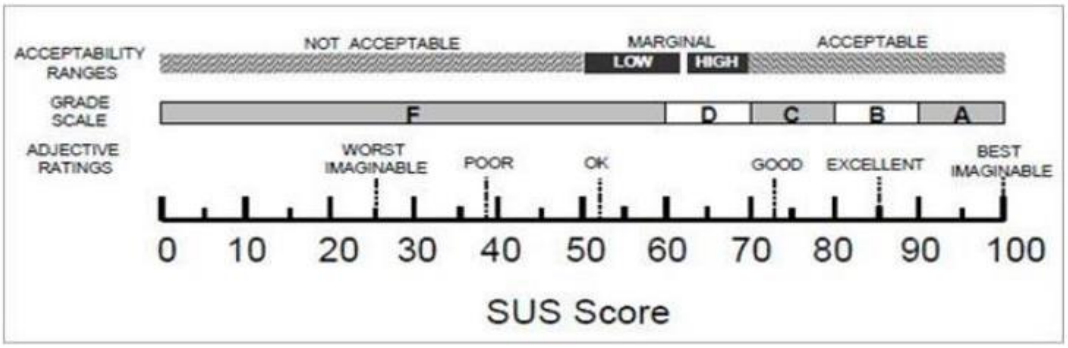

Figure 4 System Usability Scale

Based on the analysis results from the testing phase, Edurail Railway Simulation application was found to be suitable for enhancing the target users' understanding of Railway operation. All three main objectives of the project were successfully achieved: first, designing visually appealing and user-friendly 3D models and user interfaces; second, developing the Edurail Railway Simulation application using virtual reality (VR) technology on the Android platform; and third, conducting functional testing and user acceptance testing after the development phase was completed.

5. Conclusion

Edurail: Railway Simulation is successfully created as an innovative, simulation- based learning application for railway training. The application meets all main project objectives, such as creating interactive and educational content. Delivering user-friendly experience and determining level of user acceptance. Usability testing results are indicating high satisfaction, with users responding positively to both the learning value and the usability of the application. By combining engaging gameplay with realistic simulation situations, Edurail is offering a very effective and engaging learning experience. While the system is complete and functions as intended to achieve its expressed goals, several potential improvements have been conceived for future development. Some include the addition of more simulation content, more advanced interactive features, and increased realism with improved visual and mechanical components, With these, Edurail : Railway Simulation stands a lot of potential to become a comprehensive and efficient digital learning system for railway training.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:****Nabil nurHakimi Bin Abdul Rasid, Norhalina Senan;* ***data collection:*** *Nabil nurHakimi Bin Abdul Rasid, Norhalina Senan;* ***analysis and interpretation of results:*** *Nabil nurHakimi Bin Abdul Rasid, Norhalina Senan;* ***draft manuscript preparation:*** *Nabil nurHakimi Bin Abdul Rasid, Norhalina Senan. All authors reviewed the results and approved the final version of the manuscript.*

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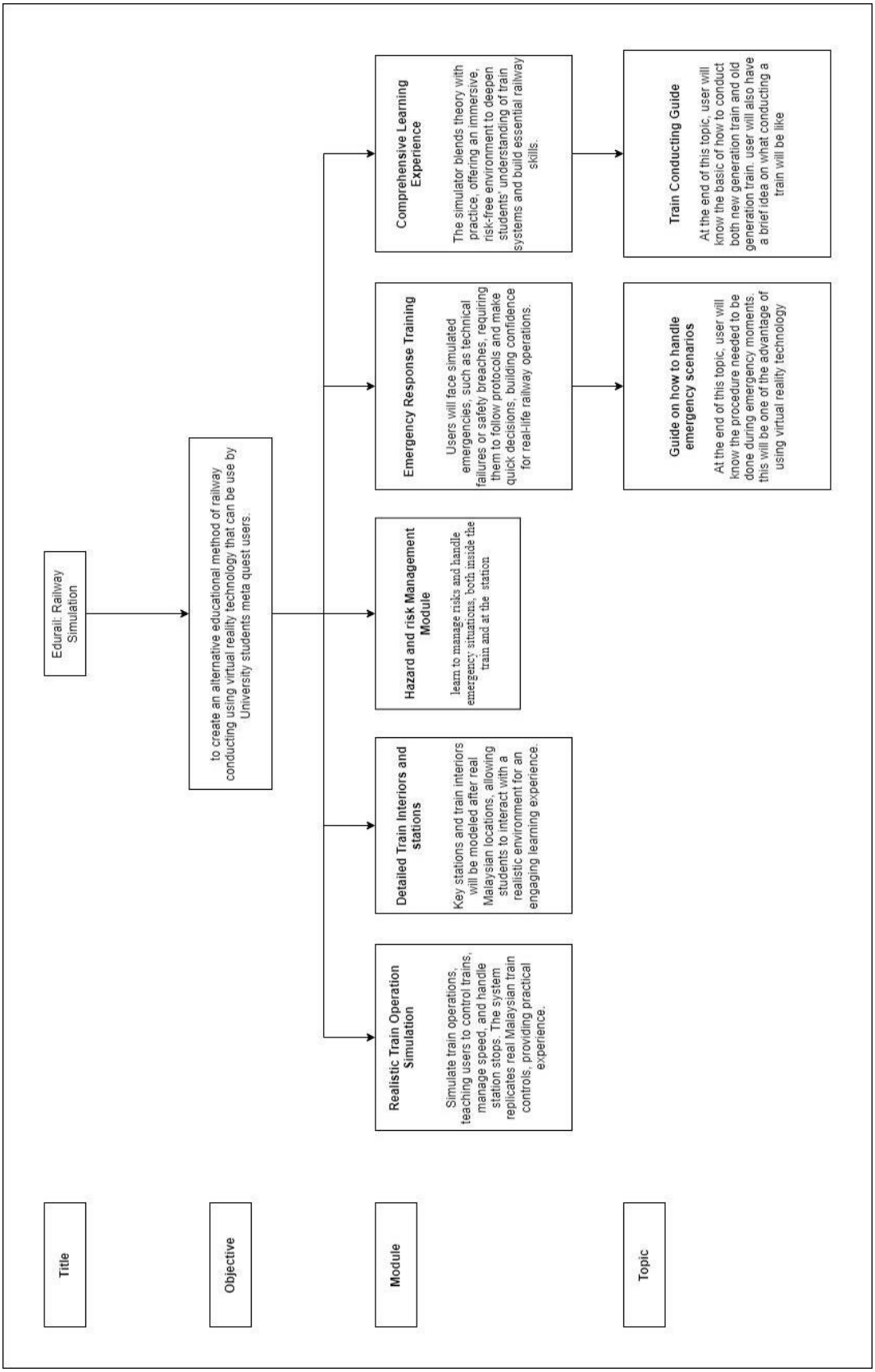
Appendix A:

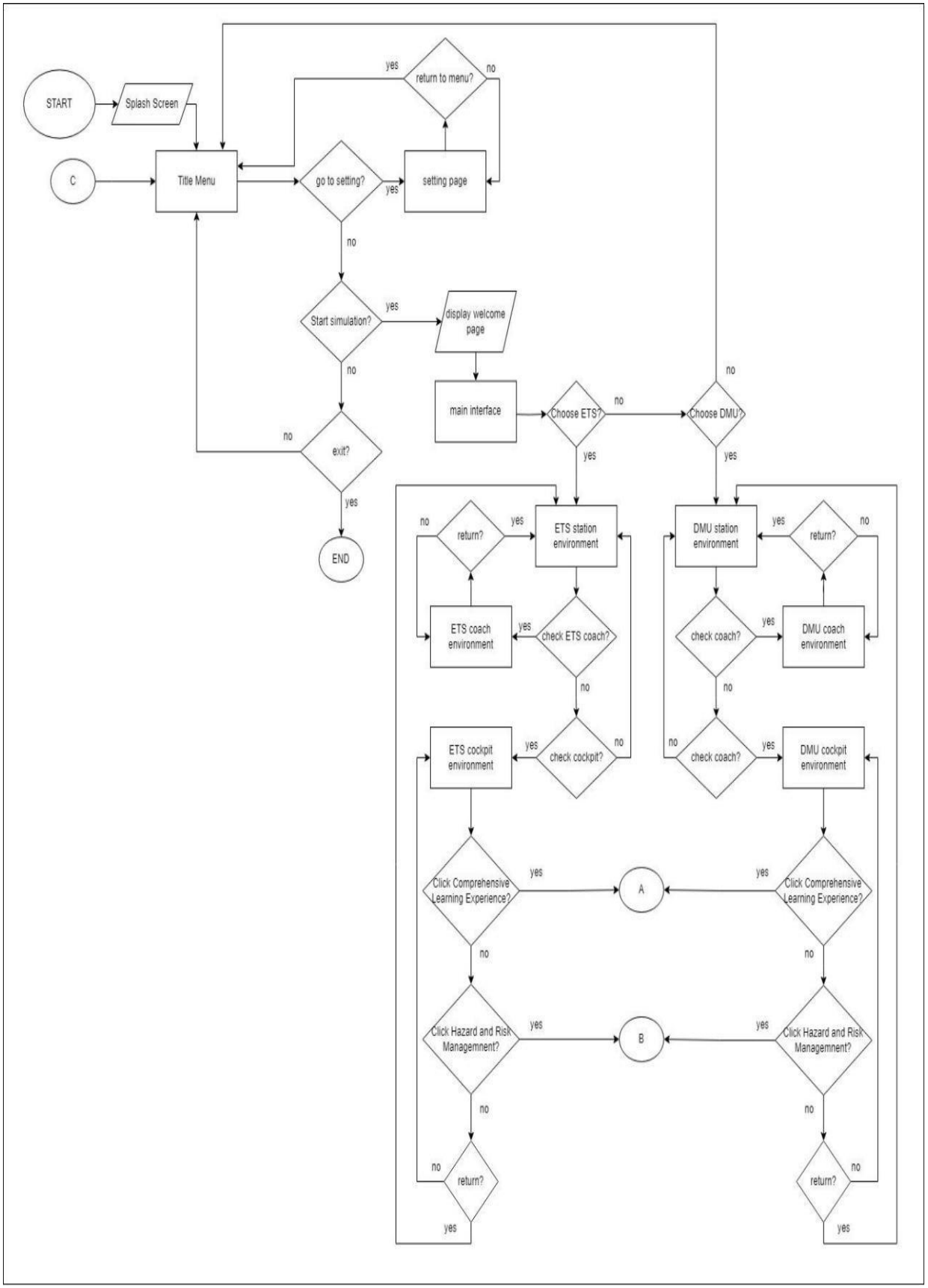
Content Structure



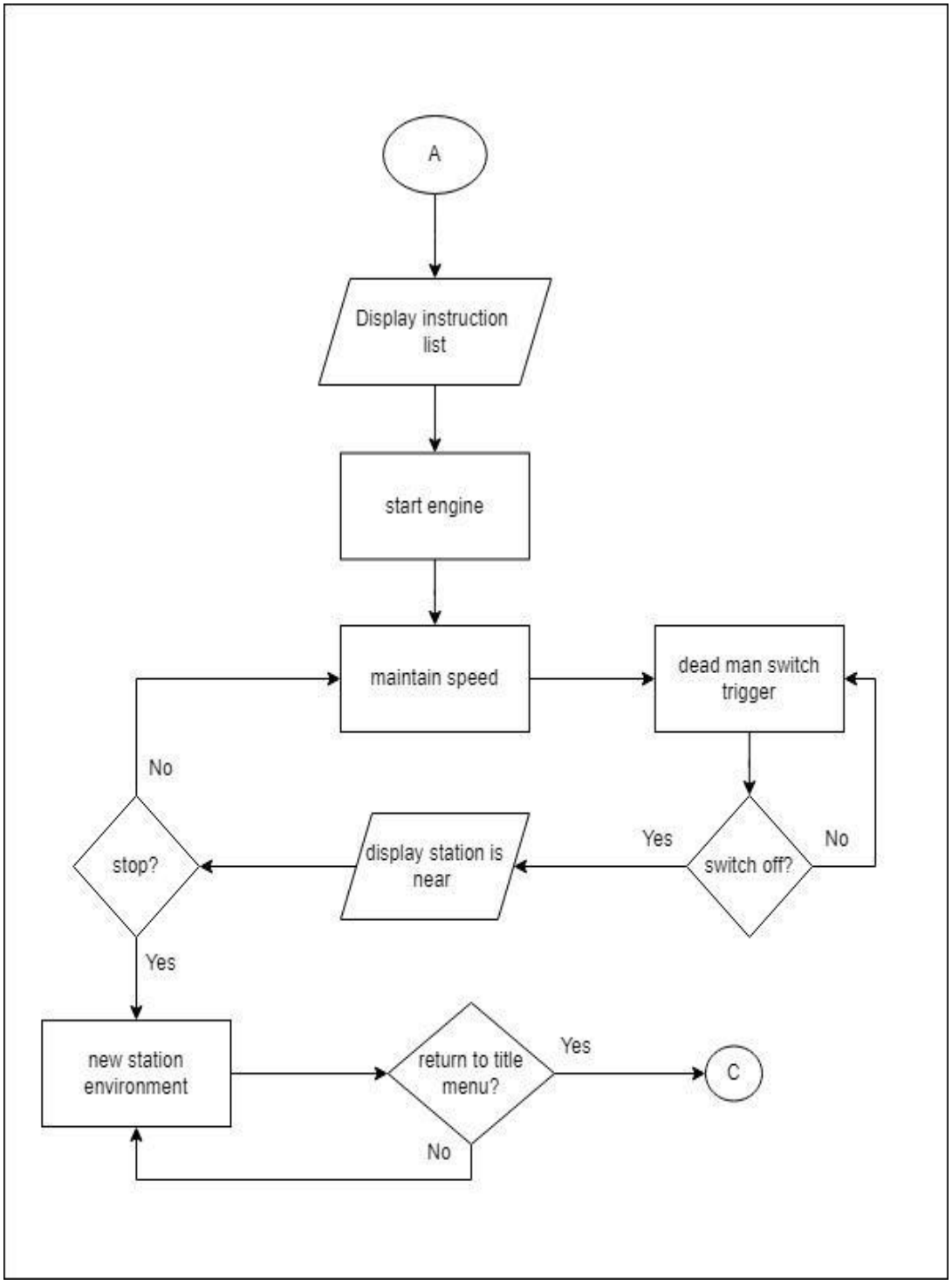
Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Appendix B:

Flowchart for Edurail Railway Simulation

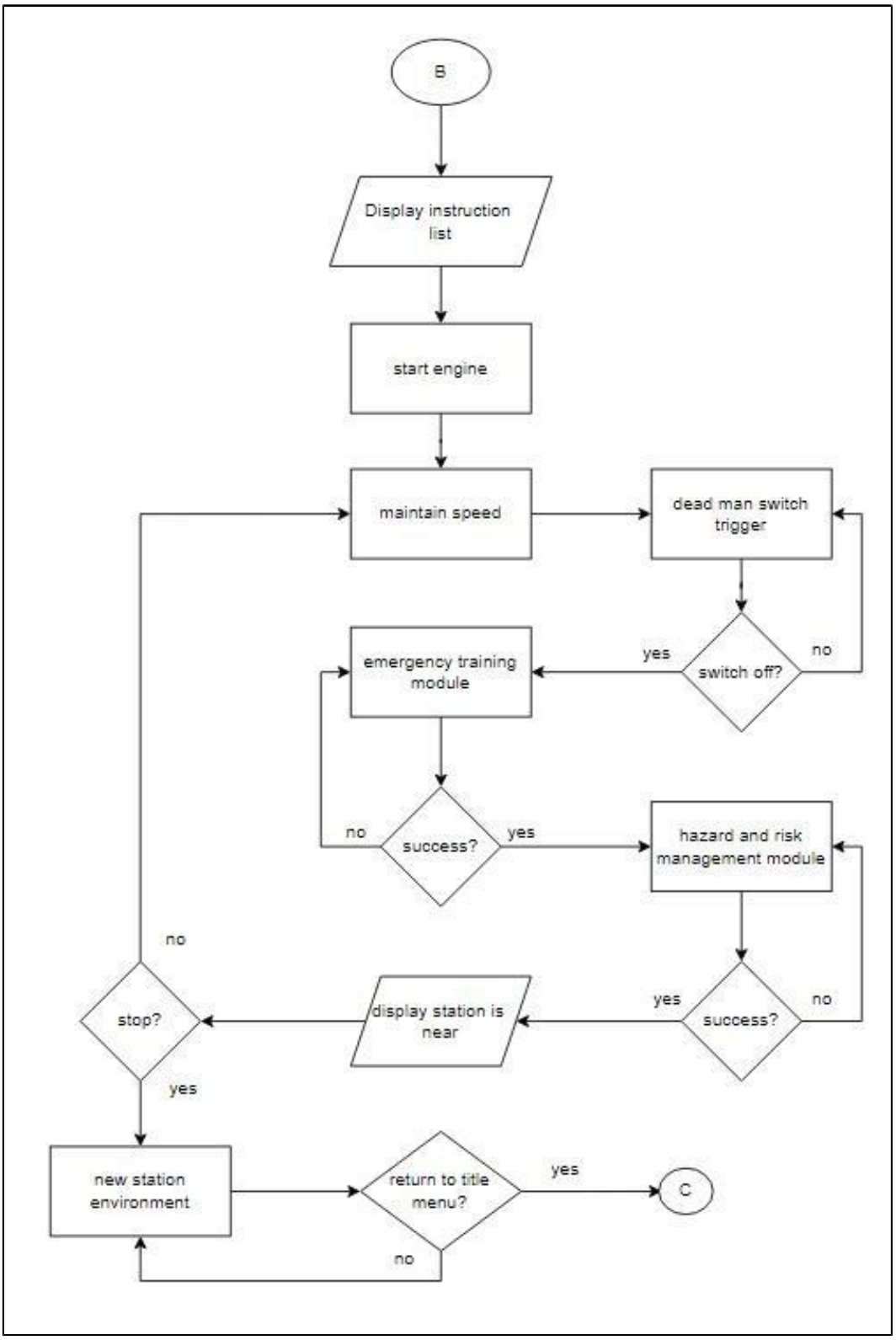


Flowchart for Comprehensive learning



Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Flowchart for Hazard and Risk Management



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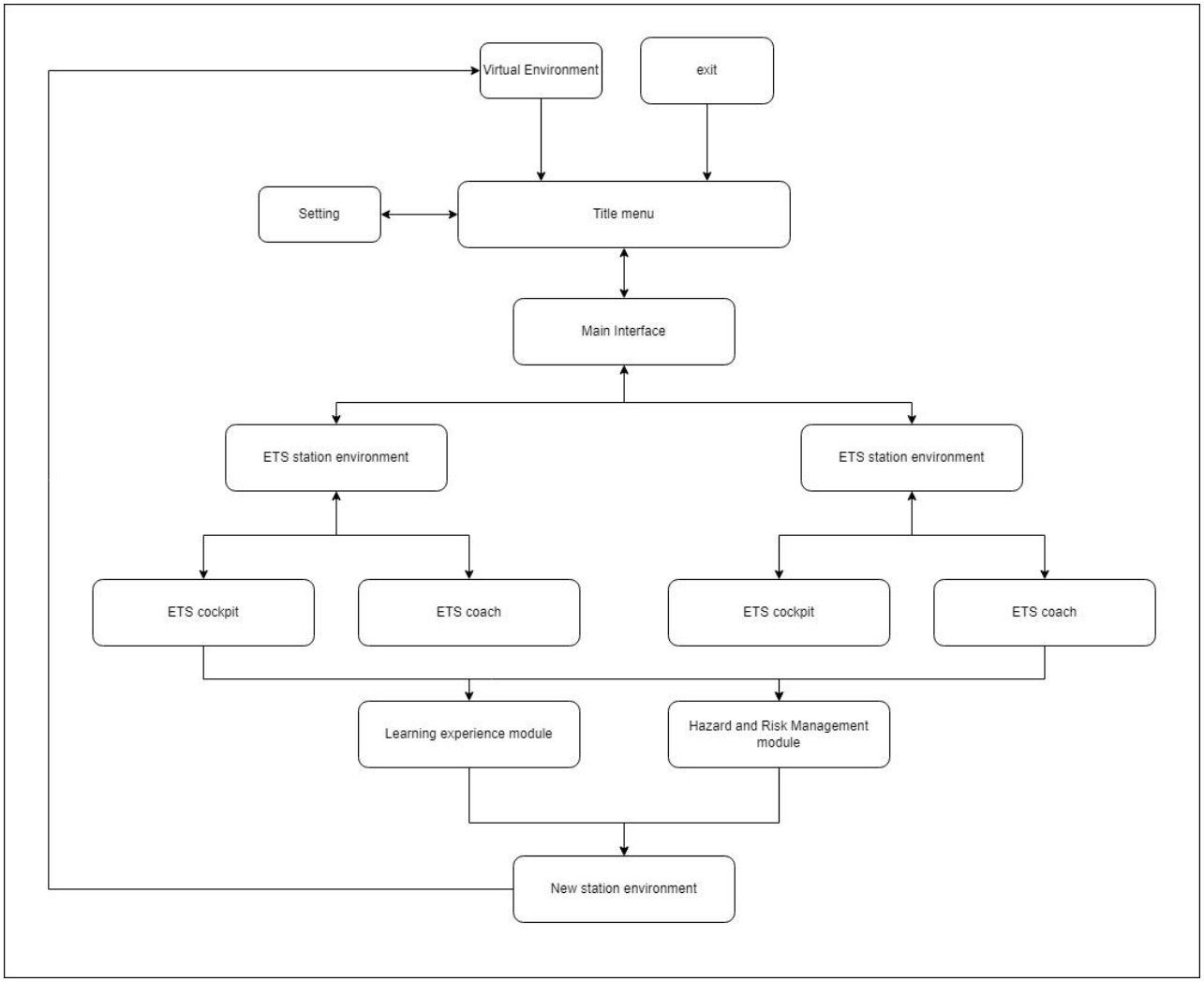
Appendix C:

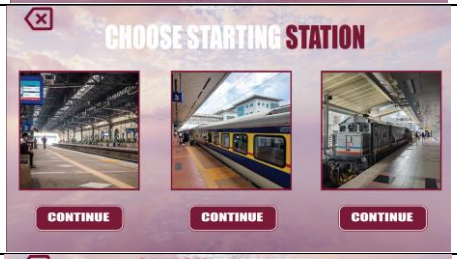
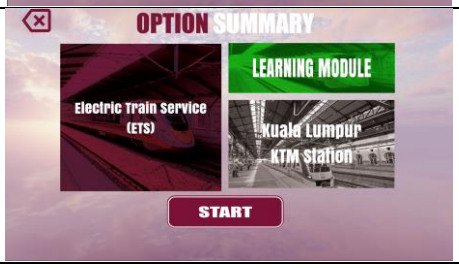
Navigational Structure



Applied Information Technology and Computer Science Vol. 7 No. 1 (2026) p. 274-293

Appendix D

Interface Design

Interface	Description
	Edurail : Railway Simulator Main Menu. User will be greeted with this interface on every startup
	Homepage. In this panel, user can view various information about the system. User can then choose the module prepared within the simulation. Learning Moduule and Emergency Module.
	Train selection panel. In this panel, user can select what train they want to use. Between Electric Train Service (ETS) or KTM Class 25 (Locomotive). User will play the train choosen throughout the simulation.
	Station selection menu allow user to choose what starting station they want to use. The system will spawn user according to the choosen train station.
	This is the summary panel for all the selection that the user have choosen. Once the user is ready, pressing start will initiate the simulation with the customized preference choosen by the user

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Appendix E

Testing with FTK students in UTHM Pagoh