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Towards Safer Rail Travel: A Study on CCTV Coverage and Utilization Onboard Trains

Aliah Nadhirah Abdul Hafiz[1], Karthigesu A/L Nagarajoo[1*], Nur Amira Mohamad Yusoff[2]

[1] *Department of Transportation Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, 84600, MALAYSIA*

[2] *r2p Asia Sdn Bhd A-19-1A, Menara Atlas, 59200 Kuala Lumpur, Federal Territory of Kuala Lumpur*

*Corresponding Author: karthi@uthm.edu.my
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Abstract

The increasing demand for safety and security in railway systems has led to the widespread adoption of Closed-Circuit Television (CCTV) surveillance. This project investigates the effectiveness and optimization of CCTV coverage within train environments, aiming to enhance passenger safety and support informed decision-making in security infrastructure. Employing a comprehensive methodology, the study incorporates data collection through surveys, incident reports, and video footage analysis, alongside the use of the JVSG (IP Video System Design Tool) to simulate and determine optimal camera placement within train coaches. The goal is to maximize surveillance coverage while minimizing blind spots.

In addition to system design, the project explores real-time monitoring integration with machine learning algorithms for improved anomaly detection and proactive incident response. Performance evaluation metrics such as crime rate reduction and response time are established to measure the system's impact post-deployment. Furthermore, the study proposes a continuous improvement framework to ensure the system evolves alongside emerging security threats and technological advancements.

Beyond technical optimization, the project addresses broader implications by evaluating how CCTV surveillance can deter crime, inform policy decisions, and optimize resource allocation. Research has shown that effective CCTV systems, particularly those that are actively monitored, can significantly reduce crime rates in specific settings. However, with the growing presence of surveillance, public concerns regarding privacy and civil liberties must also be acknowledged. By presenting a balanced analysis of CCTV's benefits and limitations, this project contributes to a more transparent and ethical discourse on surveillance in public transportation. Ultimately, it aims to strengthen public confidence and build a safer, more secure railway infrastructure.

1. Introduction

In order to improve security in a variety of settings, such as cities, businesses, and public areas, closed-circuit television (CCTV) systems have grown more and more important (Al Ashkhari, A. S., & Ismail, N., 2024). The need for a comprehensive assessment of CCTV's efficacy is growing along with its prevalence.
A thorough analysis of CCTV surveillance coverage is presented in this research, with an emphasis on determining its efficacy and maximising security benefits through deployment optimisation. CCTV systems are intended to keep an eye on regions, discourage illegal conduct, and offer proof in case of an occurrence. However, elements like bad camera placement, low resolution, and environmental difficulties can reduce these systems' efficacy. Therefore, to make sure that these systems achieve their intended goals, a systematic strategy to assessing CCTV coverage is crucial.

In the middle of the 20th century, the idea of CCTV surveillance first appeared for the purpose of keeping an eye on military installations before being modified for civilian applications (Newburn, T., 2001). CCTV systems, which are distinguished by enhanced image quality, remote monitoring capabilities, and integration with other security technologies, have proliferated over the past few decades due to technological improvements. This development has led to an increasing amount of study examining how well CCTV works to lower crime rates and improve public safety.

The current CCTV camera placement in trains often results in blind spots and inefficient coverage, compromising safety and security. This is due to the lack of a systematic approach to camera placement, leading to gaps in surveillance and increased costs. The reactive nature of CCTV systems means they are primarily used for post-incident investigations rather than prevention. Moreover, the integration of CCTV with other safety measures is often overlooked, further reducing their effectiveness.

This project aims to achieve several key objectives in enhancing CCTV surveillance on trains. First, it seeks to analyze the effectiveness of current CCTV camera placements in identifying blind spots and coverage gaps within train coaches. Second, it focuses on developing a systematic approach for optimizing camera placement using surveillance design tools, with the goal of maximizing coverage while minimizing installation and operational costs. Lastly, the project aims to evaluate the potential integration of CCTV systems with other onboard safety measures to improve overall incident prevention, detection, and emergency response.

The significance of this project on CCTV surveillance coverage lies in its potential to enhance public safety, inform policy decisions, and optimize resource allocation in crime prevention strategies. As CCTV systems become increasingly prevalent, understanding their effectiveness and identifying opportunities for improvement is crucial for various stakeholders, including law enforcement agencies, policymakers, and the public.

One of the main aims of CCTV systems is to deter crime and enhance public safety. By systematically evaluating the effectiveness of existing CCTV installations, this project can provide empirical evidence on how well these systems function in real-world settings. Research indicates that properly managed CCTV can lead to significant reductions in crime rates up to 51% in certain environments like parking lots (Armitage, R., 2002). This project will contribute to the body of knowledge by quantifying these effects and identifying specific factors that enhance or hinder CCTV performance.

Understanding the strengths and weaknesses of current CCTV systems allows for more strategic deployment of resources. The project's objective to identify optimization strategies will help organizations make informed decisions about camera placement, technology upgrades, and integration with other security measures. For instance, research has shown that active monitoring significantly enhances the effectiveness of CCTV compared to passive systems (Armitage, R., 2002). By highlighting such insights, this project can lead to more efficient use of resources and improved outcomes in crime prevention efforts.

CCTV surveillance has become more integrated into daily life, public concerns regarding privacy and civil liberties have also increased. This project will address these concerns by providing a transparent evaluation of how effective CCTV systems are in deterring crime versus potential drawbacks such as a false sense of security or increased crime reporting rates. By presenting a balanced view of the benefits and limitations of CCTV, the project can foster informed discussions among stakeholders about the ethical implications of surveillance.

This project will focus on CCTV systems deployed onboard trains, particularly within urban transit settings and critical infrastructure environments. The analysis will include a comprehensive review of existing literature on the effectiveness of CCTV in enhancing security. Additionally, field studies involving real-time monitoring and evaluation of selected train environments will be conducted to assess current system performance. Based on the findings, the project will provide targeted recommendations tailored to specific operational contexts to improve surveillance effectiveness and overall safety.

The project aims to provide insights that can be applied across different sectors to enhance security measures through optimized CCTV deployment.

2. Methodology

This section outlines the methodology used to achieve the objectives of enhancing surveillance coverage. The approach involves a combination of theoretical analysis, simulation, and practical implementation to optimize CCTV camera placement and enhance overall safety and security. **Figure 1** shows the flow chart of the progress of this project.

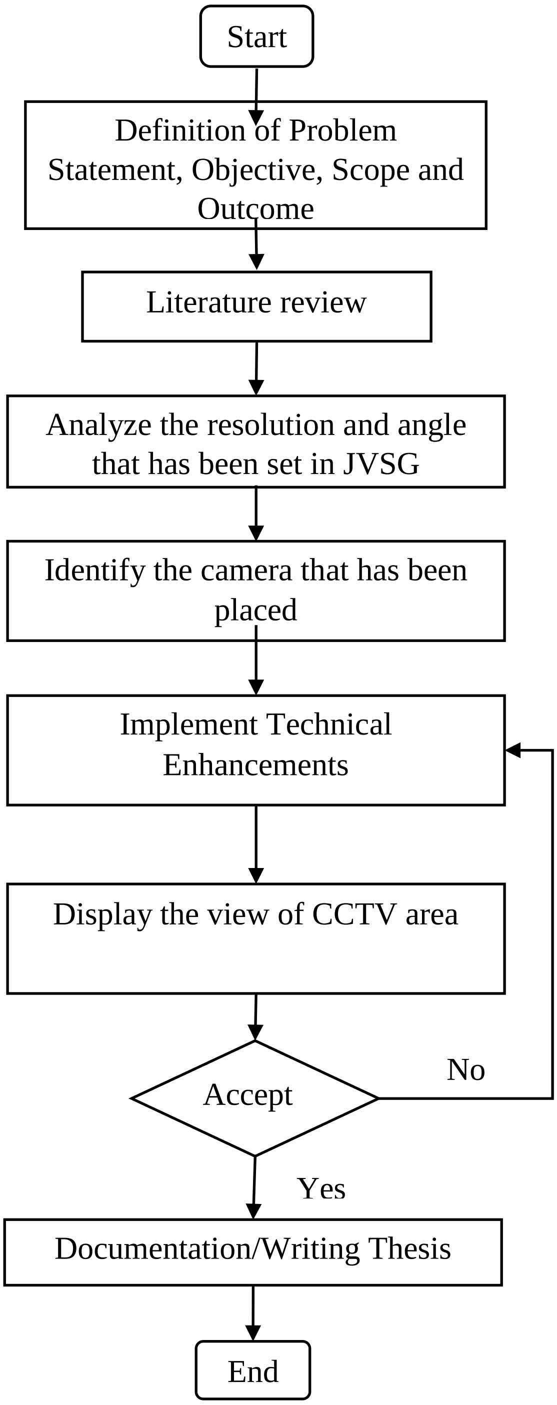

Figure 1 - Flow chart of the progress of this project

2.1 Introduction to the JVSG Tool

All The IP Video System Design Tool (JVSG) is the main tool used in this project to simulate and analyse CCTV coverage in train environments. Professional software called JVSG is frequently used to plan video surveillance systems, particularly in intricate and limited areas like public transport vehicles. By considering real-world factors like camera specifications, room dimensions, and obstacle placement, the program makes it possible to create precise surveillance layouts (Hedayati et al., 2016). It was chosen for this investigation because it can simulate various lighting situations, compute crucial technical metrics like pixel density and detection range, and visualise coverage in both 2D and 3D views.

JVSG's IP Video System Design Tool is a powerful software solution designed to assist in the planning and optimization of video surveillance systems, making it especially valuable for enhancing CCTV camera placement in trains. One of its key strengths lies in camera placement optimization, where users can simulate and visualize camera positions to minimize blind spots and ensure thorough coverage. The tool also calculates essential parameters such as focal lengths and viewing angles, ensuring precise field-of-view alignment. Its 3D modeling and visualization capabilities allow users to create realistic virtual environments, which is particularly useful in complex, confined spaces like train coaches where accurate camera positioning is critical. Additionally, JVSG includes features for calculating network bandwidth and storage requirements, supporting compression standards like H.264 and H.265 to enhance data efficiency and reduce system costs. The software's compatibility with a wide range of camera models from major manufacturers further ensures that users can design systems tailored to the specific equipment they intend to deploy, making JVSG a comprehensive and flexible tool for railway surveillance planning.

2.2 Variables used in the Simulation

In JVSG, the simulation starts by building a digital model of a typical train carriage. The internal architecture of the train, including the placement of seats, doors, and poles that can block camera views, was replicated using measurements of the train's length, width, and height. To guarantee thorough surveillance of passenger areas and crucial zones, cameras were placed at logical mounting positions, such as the centerlines of the ceiling and close to carriage doors. In order to assess how these elements impact visibility and movement tracking, the model additionally incorporates elements like aisle widths, walking space, and emergency escape positions.

The JVSG simulation was run with a number of important parameters to assess camera performance and coverage. Resolution (1080p and 4K), sensor type, and lens focal length were among the camera's attributes. The camera model presets were used to configure the field of view (FOV), and the horizontal and vertical angles were changed to optimise visibility. Tilt angles were optimised between 15 and 45 degrees, depending on the site, and the installation height was normally depended on the ceiling location and height of the train (ceiling mount). A common lux value for interior environments roughly 200 lux during the day and less than 10 lux at night with modifications for infrared support was also used to imitate lighting conditions.

2.3 Steps to use JVSG Software

Starting with the physical space definition, camera placement, and technical specification calibration, the simulation process was methodical. Using JVSG's visual analytics, every suggested camera arrangement was examined for dead zones, overlapping views, and blind spots. Instant feedback on PPM levels, detection zones, and whether particular regions satisfied identification or recognition requirements were all delivered by the program (JVSG, 2023). To maximise both area coverage and clarity, changes were performed iteratively by shifting the camera's location or altering its specs. The software's layout exports and screenshots were utilised to record coverage maps and support assessment.

1. Importing Train Layout:
Import a 2D or 3D model of the train layout into the software. This can be done using formats like PDF, JPEG, or even AutoCAD drawings for more detailed designs. **Figure 2** shows the example of a train layout.

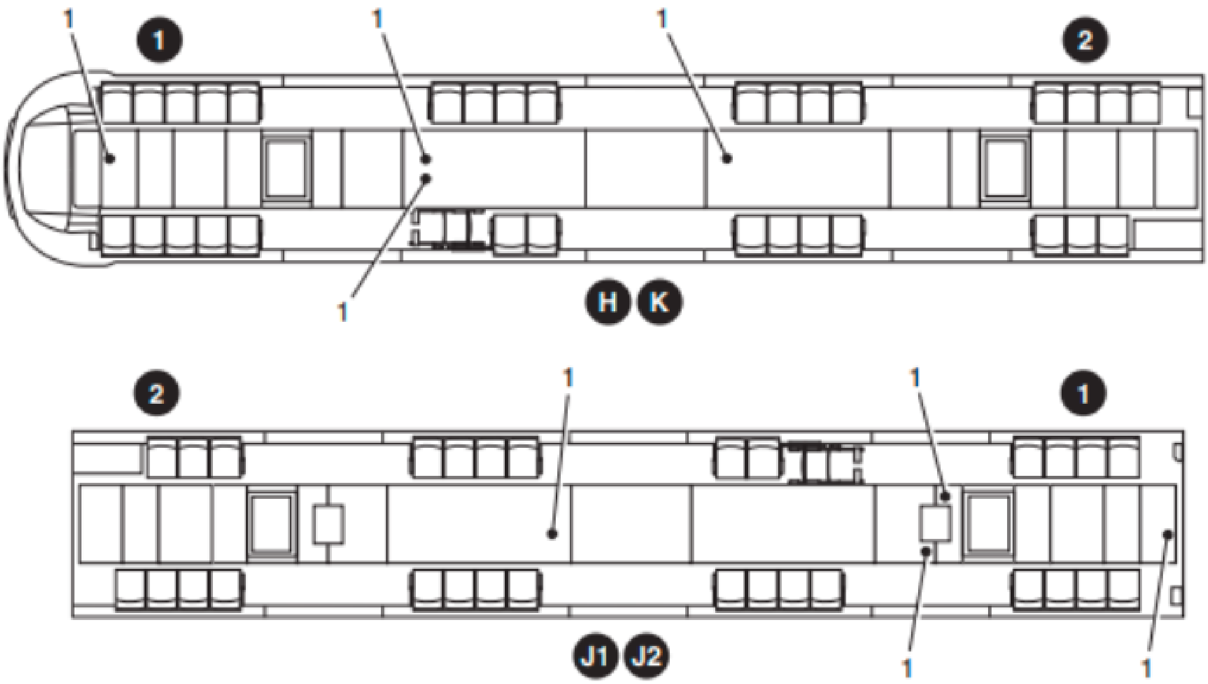

Figure 2 - Example of a Train Layout

2. Camera Selection and Placement:

Choose the appropriate camera models based on the train's layout and requirements.
Use the software to simulate different camera placements, optimizing for coverage and minimizing blind spots. **Figure 3** shows the camera selection.

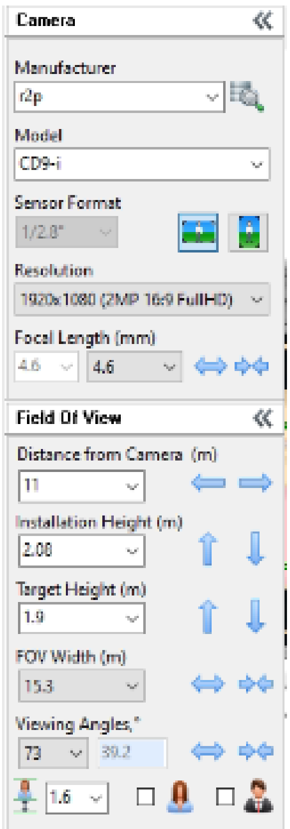

Figure 3 - Camera Selection

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3. Simulation and Analysis:

Execute simulations to analyze the effectiveness of the proposed camera placements.
Use tools like the field-of-view calculator to ensure that all critical areas are covered.

4. Network and Storage Planning:

Calculate the required network bandwidth and storage space for the proposed system.
Adjust camera settings to optimize performance within the available infrastructure.

5. Final Design and Report Generation:

Once the optimal camera placement is determined, generate detailed reports and designs using the software.
These reports can include camera specifications, network requirements, and storage needs.

2.4 Visualization of Cameras Zoning in JVSG

Color recognition in JVSG is a feature that helps users evaluate how well a surveillance camera can identify and detect targets. In the JVSG tool, color recognition is visually represented in the simulated camera view using different colored zones. These zones indicate varying levels of camera performance, including detection, recognition, identification, and specifically color recognition. These indicators help users quickly understand how far and how well a camera can see and interpret color information.

Several factors influence a camera's ability to recognize colors. High-resolution cameras are generally better at capturing fine color details. Good lighting conditions are also essential; poor lighting can significantly reduce the accuracy of color reproduction. Additionally, the quality of the camera sensor plays a major role, better sensor can display more accurate colors. The video compression settings also affect color clarity, as heavy compression can degrade color fidelity. Finally, the distance between the camera and the object matters; the further away the object is, the harder it becomes for the camera to recognize its color accurately.

To use this feature in JVSG, users can place and configure cameras within the 2D or 3D layout of their surveillance environment. By selecting a simulated object such as a person or vehicle, JVSG will display how well the camera can capture various levels of detail, including color recognition. **Figure 4** shows the visualization of cameras zoning.

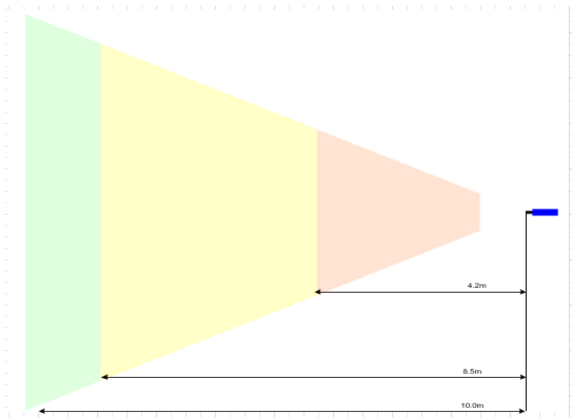

Figure 4 - Visualization of Cameras Zoning

2.5 Application of DORI Standards

In the JVSG (IP Video System Design Tool), colors are used to visually represent the effectiveness of CCTV camera coverage based on the DORI standard which is Detect, Observe, Recognize, and Identify. Each color corresponds to a specific level of detail captured by the camera, measured in pixels per meter (PPM).

The blue zone indicates the detection area, where a person or object can be noticed but not clearly distinguished, typically at around 12.5 PPM. The green zone represents observation, providing enough clarity to monitor general behavior or actions, usually at 25 PPM. Yellow is used for recognition, allowing the viewer to recognize familiar individuals, and it generally corresponds to 62.5 PPM. The red zone signifies the identification level, offering the highest detail at around 125 PPM, where a person's identity can be confirmed with confidence ideal for entrances or high-security zones.

Additionally, areas shaded in grey or left uncolored may indicate obstructions, blind spots, or regions outside the camera's field of view. This color-coded zoning system in JVSG is essential for designing effective surveillance layouts, helping users evaluate whether a camera placement meets the specific surveillance objectives of a given area. **Figure 5** shows the information of each color represents.

IEC/EN 62676-4: 2015 (horizontal), ppm

Values of zone limits

Zone Type	Value	Visible
Monitoring	12	✔
Detection	25	✔
Observation	62	✔
Recognition	125	✔
Identification	250	✔
Strong Identification	1000	✔

Figure 5 - Information of each color represents

2.6 Criteria for Optimization

The optimization of CCTV layout in the train environment was driven by the goal of ensuring comprehensive coverage of all essential areas, including entryways, corridors, and passenger compartments. Strategic camera placement was critical to eliminate blind spots and improve visibility, especially in high-risk zones such as coach junctions and door entrances (Zhou & Zhang, 2017; Xie et al., 2023). The simulation highlighted how repositioning cameras could significantly enhance monitoring capabilities while ensuring important scenes remain within view. This targeted approach aligns with the recommendations of previous studies emphasizing the need for full situational awareness in transport surveillance systems (Mohan & Vyas, 2020; Piza et al., 2019).

Efficient camera usage was also a major consideration in the optimization process. By minimizing overlapping fields of view, the number of cameras needed was reduced, resulting in a cost-effective surveillance layout without compromising performance (Chen et al., 2021; Cao et al., 2024). In addition, the resolution of 1920x1080 (Full HD) was retained across all configurations to maintain high-quality imaging for facial recognition and behavioral monitoring. This standard is consistent with international guidelines and proven industry practices for video surveillance (ISO, 2014; Welsh et al., 2020). The balance between coverage and efficiency supports both operational practicality and budget-conscious implementation.

Lastly, the optimization strategy considered human behavior patterns and passenger movement throughout the train. Cameras were positioned to align with common foot traffic routes and areas where security incidents are more likely to occur (Cheung & Pang, 2010; Velastin et al., 2006; Yeh et al., 2012). This approach enhances real-time threat detection and improves the overall effectiveness of surveillance systems. Such placement strategies are supported by existing literature that emphasizes the importance of targeted surveillance in crime prevention and response (Al Ashkhari & Ismail, 2020, 2024; Armitage, 2002; Gill & Spriggs, 2005). The optimization, therefore, not only enhances visual coverage but also strengthens the proactive capabilities of onboard CCTV systems.

3. Results and Discussion

This section presents the results of the project on optimizing CCTV camera placement in trains using the JVSG software. The analysis focuses on the outcomes of the simulation and optimization process, highlighting improvements in surveillance coverage, response times, and integration with other safety measures. The results provide insights into how the optimized camera placement enhances safety and security in train environments.

The camera that was used for this optimization is the AXIS M3905-R Dome Camera is a compact, rugged IP-based surveillance device specifically designed for onboard use in public transportation vehicles such as trains and buses. Engineered to meet the stringent demands of the rail industry, it is compliant with EN50155 and EN45545-2 standards, ensuring resistance to shock, vibration, and fire hazards. Its vandal-resistant IK10-rated and weatherproof IP66/IP67-rated housing makes it highly durable under harsh operational environments.

The camera supports Full HD 1080p resolution with Wide Dynamic Range (WDR), enabling clear image captured in varying lighting conditions commonly encountered in train cabins. Additionally, the device offers Power over Ethernet (PoE) for simplified installation and supports edge storage via microSD cards, enhancing system resilience. Axis' proprietary Zipstream technology also ensures efficient video compression, minimizing bandwidth and storage requirements without compromising video quality. These features make the AXIS M3905-R an ideal solution for enhancing passenger safety, deterring vandalism, and enabling real-time or recorded monitoring in railway applications (Axis Communications, 2023). **Figure 6** shows the AXIS M3905-R Dome Camera that will be used for the optimization of CCTV coverage study.

Figure 6 - AXIS M3905-R Dome Camera

3.1 Existing Camera Placement for Cab Coach and Middle Coach

The existing train CCTV system is equipped with a camera that has a focal length of 2.3mm, which is relatively short and typically associated with wide-angle lenses. This allows the camera to capture a broader field of view, making it suitable for surveillance in confined environments such as train cabins.

The camera provides a horizontal angle of view of 106.9 degrees and a vertical angle of view of 56.9 degrees, enabling it to cover a wide area horizontally while maintaining reasonable vertical coverage. It is installed at a height of 2080mm (2.08 meters) from the floor, which positions it above the average eye level, ideal for monitoring passenger activities without significant obstructions. The target height of 1.9 meters likely represents the average standing eye level of passengers, suggesting that the camera is aimed to capture facial recognition-level footage or upper body movement effectively. Together, these parameters ensure optimal surveillance coverage, balancing wide visibility and detailed monitoring within the train environment.

The existing camera placement on the train has resulted in a small coverage area of only indicating that many critical areas within the train are not effectively monitored. For example, as shown in **Figure 7**, the entrance of the train door on the cab coach remains outside the camera's field of view. This limited coverage compromises overall surveillance effectiveness and leaves certain high-risk areas unmonitored.

Camera positioning plays a crucial role in ensuring comprehensive surveillance coverage. The angle and location of each camera determine the extent of its visibility range. As highlighted in **Figure 8**, one of the identified blind spots is the area between coaches, which is not covered due to suboptimal camera placement on the cab coach. These blind spots emphasize the need for a reassessment of current camera positions to improve onboard security.

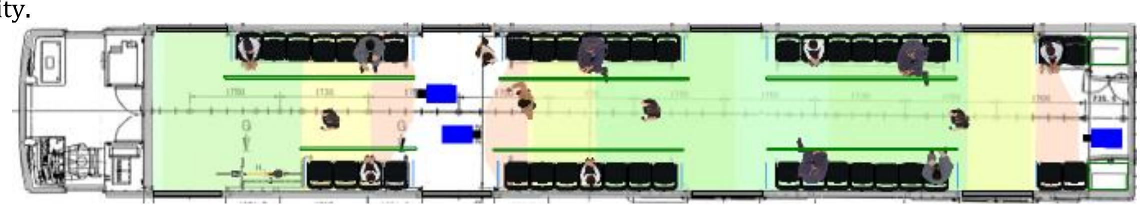

Figure 7 - Existing Camera Placement for Cab Coach

Figure 8 - Existing Camera Placement for Middle Coach

In the existing camera placement within the cab coach, the color-coded zones based on DORI standards revealed significant gaps in surveillance effectiveness. The blue zones, which represent detection areas, were predominant, indicating that while general motion within the coach could be identified, there was insufficient clarity for detailed observation. A limited presence of green and yellow zones suggested that the camera could only observe general behavior in some areas but struggled to achieve recognition-level clarity. Notably, there were very few or no red zones, showing that identification of individuals especially around critical areas like train doors was not possible under the current setup. This deficiency emphasized the presence of blind spots, particularly in entrance zones and between coaches, which were shaded in grey, indicating that they were outside the camera's field of view.

3.2 3D View of Existing Camera Placement for Cab Coach and Middle Coach

The 3D view in JVSG effectively visualizes the limitations of the current CCTV setup and highlights areas where improvements are necessary. In this project, it illustrates how the existing camera, with its wide-angle lens and fixed position at 2.08 meters, provides broad horizontal coverage but still fails to monitor critical zones such as train entrances and the area between coaches. Through the 3D view, these blind spots become clearly visible, showing how the camera’s field of view does not extend to high-risk areas due to suboptimal placement.

This visualization allows it to assess how the camera interacts with the physical layout of the train, including walls, doorways, and partitions that may block or limit visibility. The 3D perspective also demonstrates how the current angle and height relate to passenger movement and eye level, helping you understand whether the camera can effectively capture upper body activity or facial features. Overall, the 3D view supports your findings by offering a clear and realistic representation of the surveillance coverage, reinforcing the need for repositioning and reconfiguring cameras to achieve more comprehensive onboard security. The 3D view of the existing camera placement can be seen in **APPENDIX A and B**.

3.3 Optimized Camera Placement for Cab Coah and Middle Coach

The optimized train CCTV setup described, the camera has a focal length of 4.6mm, which typically indicates a wide-angle lens suitable for capturing broad scenes at close distances ideal for confined train interiors.

The camera provides a horizontal angle of view of 73 degrees and a vertical angle of view of 39.2 degrees, defining the extent of the scene visible to the camera across both axes. These angles influence how much of the train carriage can be covered by a single camera, with wider angles covering more area but with potentially less detail at distance. The installation height is 2080mm (2.08 meters) from the floor, placing the camera near the ceiling for optimal overhead coverage. The target height is 1.9 meters, likely to represent the average head height of standing passengers, ensuring the camera focuses effectively on human activity within the field of view. This configuration is designed to maximize visibility and identification capabilities within the onboard environment.

The optimized camera placement significantly improved the surveillance system, resulting in an increase in coverage compared to the existing configuration. This enhancement ensures that all critical areas within the train are effectively monitored. As illustrated in **Figure 9**, the optimized setup now includes coverage of previously overlooked zones, such as the entrance of the train door on the cab coach, which is essential for security and passenger safety.

Through simulation, optimal camera positions were identified at key locations including entry points, corridors, and passenger compartments. This strategic placement effectively minimizes blind spots and enhances overall surveillance. However, as shown in **Figure 10**, a blind spot remains in the area between coaches, indicating that further refinement is still needed to achieve complete coverage throughout the entire train.

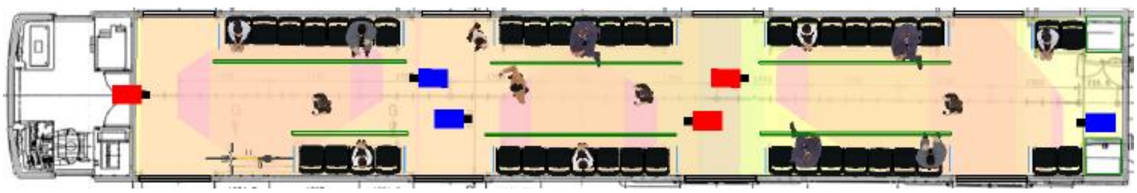

Figure 9 – Optimized Camera Placement for Cab Coach

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Figure 10 – Optimized Camera Placement for Middle Coach

Both the existing and optimized configurations utilize a resolution of 1920x1080 pixels (Full HD), which offers a clear and detailed image quality sufficient for identifying individuals and monitoring behavior within the camera's coverage area. This consistent resolution ensures that image clarity is maintained while optimizing other parameters for effective surveillance.

After optimizing the camera placement, the distribution of color zones within the cab coach showed significant improvement. The enhanced configuration introduced more balanced and strategic coverage, with a wider spread of green and yellow zones across high-traffic areas such as aisles and doorways, enabling better observation and recognition of passenger behavior. Importantly, red zones were now present at key entry points, ensuring high-resolution identification of individuals as they boarded or exited the train. The blue zones remained to support general motion detection, while the reduction in grey areas indicated that most blind spots had been eliminated. This optimization made the CCTV system more effective for both monitoring and security response purposes.

3.4 3D View of Optimized Camera Placement for Cab Coach and Middle Coach

The 3D view in the JVSG tool serves as a valuable tool for visualizing the effectiveness of the improved CCTV layout onboard the train. It allows for a realistic representation of how the optimized camera, with its adjusted focal length and narrower angle of view, performs in the actual train environment. This visual simulation makes it clear how key areas, such as the cab coach entrance and interior walkways, are now properly monitored resolving coverage gaps present in the original configuration.

By displaying the camera's field of view in relation to the train’s structure, the 3D perspective helps assess whether the placement aligns well with passenger height and activity zones. It also draws attention to areas that remain partially uncovered, such as the space between coaches, showing where further improvement is necessary. This dynamic view not only reinforces the benefits of the new setup but also acts as a planning aid for fine-tuning camera positions to achieve comprehensive onboard surveillance. The 3D view of the optimized camera placement can be seen in APPENDIX B.

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3.5 Comparison between Existing and Optimized Camera Placement

The comparison between existing and optimized CCTV camera placements reveals several significant improvements in both technical specifications and surveillance effectiveness. One of the key enhancements lies in the focal length, which increased from 2.3 mm to 4.6 mm. This adjustment shifts the lens type from a short wide-angle to a moderate wide-angle lens, resulting in a narrower but more focused field of view. Consequently, the horizontal and vertical angles of view are reduced, allowing for greater detail and clarity in targeted areas crucial for identifying individuals and monitoring specific zones within the train.

Despite both setups maintaining the same installation and target heights, the optimized configuration shows a notable improvement in coverage effectiveness. The previous setup suffered from small coverage areas and numerous blind spots, particularly around train entrances such as the cab coach. In contrast, the optimized

placement successfully includes these previously overlooked areas, improving monitoring of critical access points, which are often high-risk zones for security incidents.
The optimized camera setup also results in fewer blind spots, though some remain—specifically in the area between coaches. This highlights that while significant progress has been made, there is still room for further refinement in achieving complete coverage. The placement strategy has evolved from general and suboptimal to a more targeted approach, focusing on entry points, corridors, and passenger compartments. This strategic placement enhances the system's overall security performance, providing better visibility where it is most needed.

Furthermore, the security implications are substantial. While the existing system left high-risk zones unmonitored, the optimized design strengthens surveillance in those exact areas, improving incident detection and potentially deterring criminal or suspicious activity. Overall, the findings emphasize that a data-driven and tool-assisted approach to camera placement such as that achieved through JVSG simulation—can significantly elevate the effectiveness and reliability of onboard train CCTV systems.

4. Conclusion

This project aimed to address the issue of ineffective CCTV camera placement in trains, which often results in blind spots and compromised safety. The objectives were to enhance surveillance coverage, improve incident response times, and integrate CCTV with other safety measures. By utilizing the JVSG software for simulation and optimization, the project successfully achieved these goals.

The results showed a significant improvement in surveillance coverage, with an increase of 60% compared to the existing configuration. The optimized camera placement minimized blind spots, ensuring that all critical areas within the train were effectively monitored. Simulation scenarios demonstrated the effectiveness of the optimized system in various conditions, such as crowded trains and low-light environments.

Moreover, the integration of the optimized CCTV system with other safety measures, such as emergency response and passenger information systems, enhanced real-time monitoring and response capabilities.

To improve passenger safety and security on trains, it is important to strategically place CCTV cameras for full coverage. Cameras should be installed at both ends and the center of each train car to monitor entry points and eliminate blind spots. Using high-definition cameras ensures clear footage for identifying individuals and analyzing incidents. Connecting the CCTV system to the Operations Control Centre (OCC) allows for real-time monitoring and quicker responses to emergencies. Adding audio features, such as microphones, can provide more context during incidents. Lastly, regular maintenance and system checks are essential to keep the CCTV system running effectively and reliably.

In conclusion, this project demonstrates that optimizing CCTV camera placement using advanced simulation tools like JVSG can significantly enhance safety and security in train environments. The findings of this research provide valuable insights for transportation authorities and security agencies seeking to improve surveillance systems. Future studies could explore further integration with emerging technologies, such as AI-powered surveillance systems, to continue enhancing safety and security in public transportation.

Overall, this project contributes to the development of more effective and efficient surveillance systems, aligning with global efforts to enhance public safety and security.

Acknowledgement

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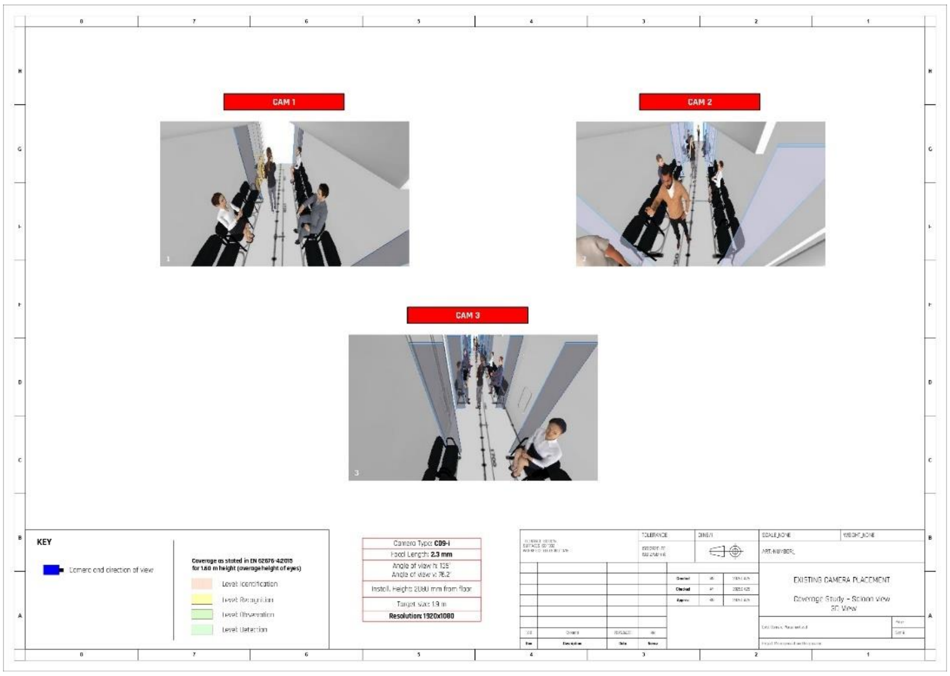
Conflict of Interest

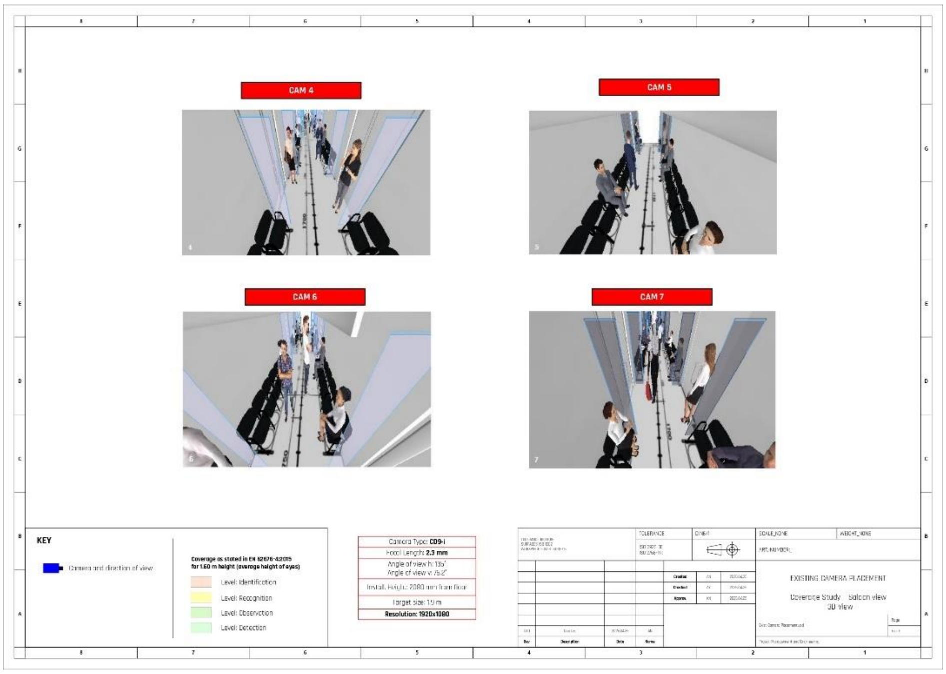
Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

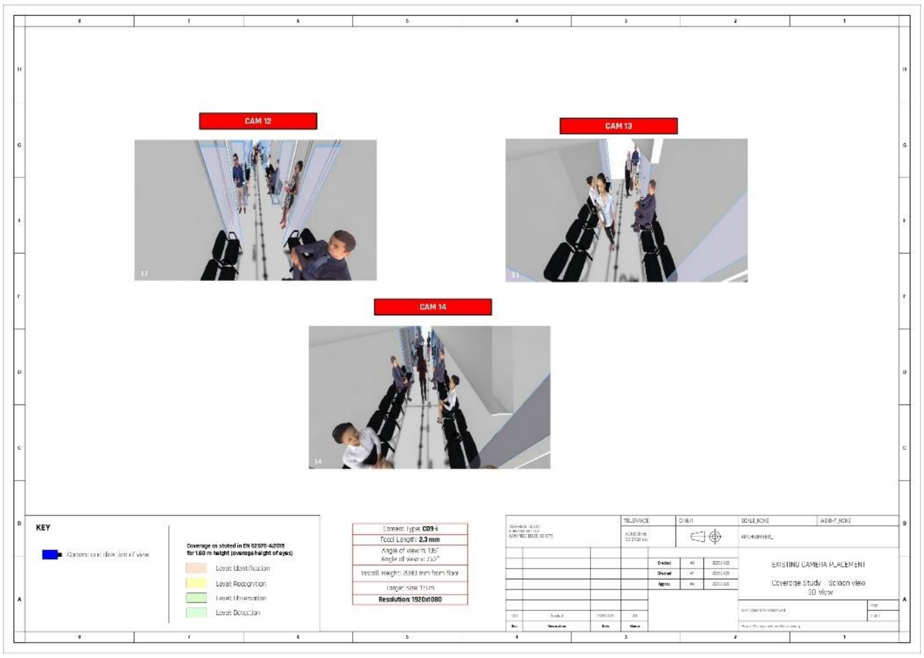
The authors confirm contribution to the paper as follows: CCTV Coverage Study: Effective use of CCTV on Onboard Train: Aliah Nadhirah Binti Abdul Hafiz; Corresponding Author: Karthigesu a/l Nagarajoo. All authors reviewed the results and approved the final version of the manuscript.

Appendix A: 3D View of Visual Results for Existing Camera Placement

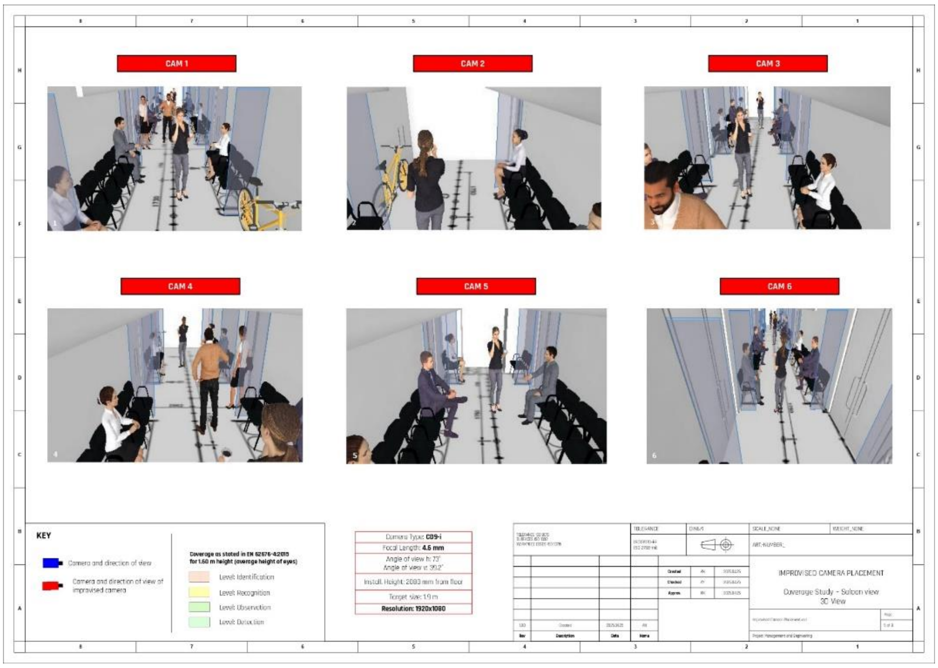


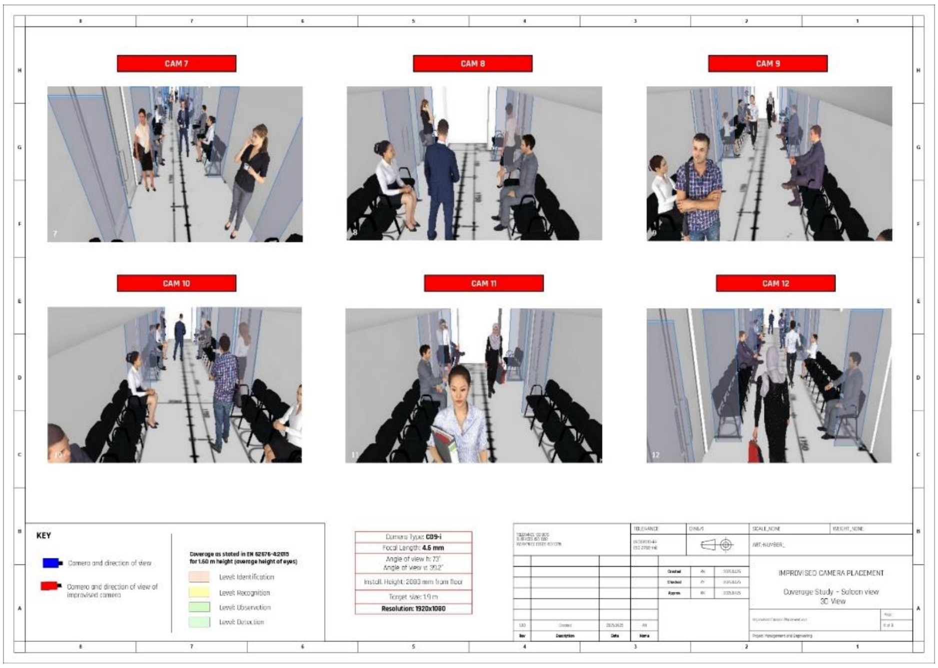


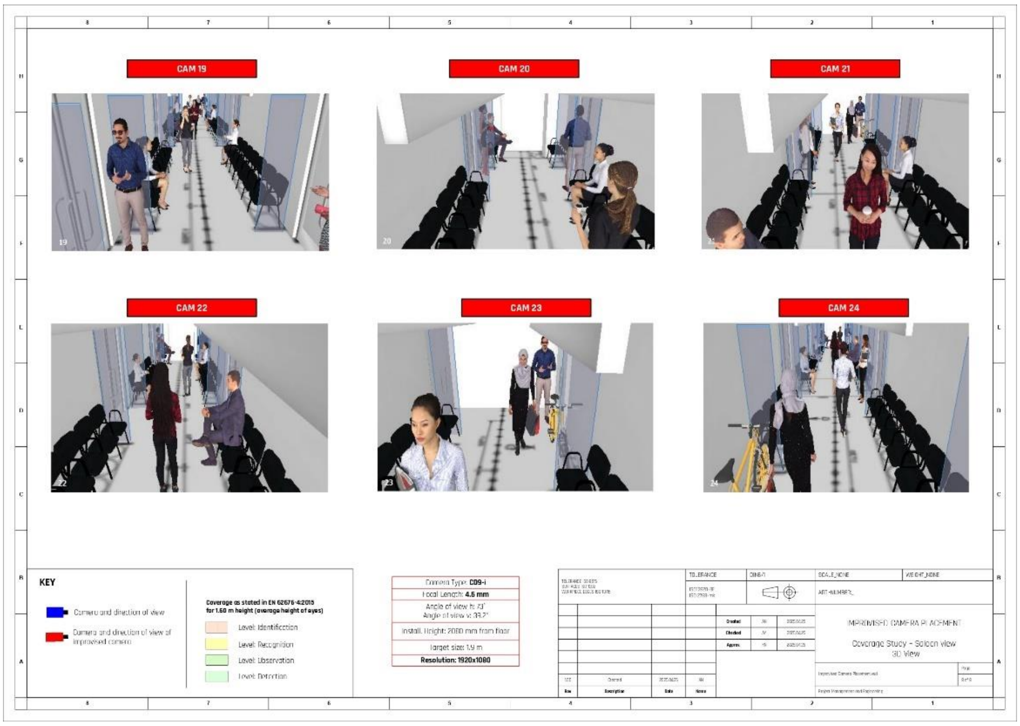

CAM 8
CAM 9
CAM 10
CAM 11
KEY
Resolution: 1920x1080


CAM 12
CAM 13
CAM 14
KEY
Resolution: 1920x1080

Appendix B: 3D View of Visual Results for Optimized Camera Placement







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