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## Application of Arduino-based Control System Hydraulic Barricades to Improve Safety at Level Crossing Safety


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### Abstract

Level crossings in Indonesia, particularly unguarded ones, experience frequent accidents, necessitating innovative safety solutions. This study aims to develop a servo-driven barricade system using an Arduino Uno microcontroller and infrared sensors to enhance safety at level crossings by preventing vehicle crossings during train passages. The research was conducted through a structured process involving both online coordination via communication platforms and offline activities at the Faculty of Transportation and Logistics Engineering, Institute of Transportation and Logistics Trisakti, and a vendor in Ciputat from April to August 2024. The methodology encompassed problem identification, conceptualization, system design with a 1:50 scale miniature, prototyping of a 1:10 scale iron barricade, testing in controlled environments, and evaluation of sensor and servo motor performance. Findings indicate that the system consistently detected train arrivals with 100% sensor accuracy and actuated barricades within 2 seconds, effectively blocking traffic in simulations and miniature tests. This research concludes that the servo-driven barricade system offers significant potential to improve safety at level crossings, with recommendations for field trials to assess environmental resilience and integration with Internet of Things technology for real-time monitoring to enhance scalability and effectiveness.



### Keywords

Arduino Uno, Barricade, Internet of Things, Level Crossing Automation, Microcontroller, Railway Safety.

## 1. Introduction

Level crossings, intersections between roads and railways, are critical points prone to accidents in Indonesia, with over 3,000 unguarded crossings contributing to approximately 500 accidents annually, resulting in significant casualties and economic losses (Siregar & Wibowo, 2022; Antono, 2023; Leliana et al., 2023). These incidents primarily occur at unguarded or illegal crossings, where the absence of gates or human guards increases risks for vehicles and pedestrians (Prasetyo & Susilo, 2020; Iswanto et al., 2021). To mitigate these hazards, research has explored automated safety systems using microcontrollers and sensors to control crossing gates and enhance traffic discipline (Sanjaya, 2017; Kusriyanto & Wismoyo, 2017; Rahman et al., 2021).

Level crossings are divided into two types, namely official guarded or unguarded level crossings and unofficial or illegal level crossings (Iswanto et al., 2021). Railway level crossings are one of the points prone to traffic accidents in Indonesia. As an effort to improve safety, level crossings have been closed and other safety improvement efforts have been carried out (Mahmud et al., 2015; Dewi & Santoso, 2019). Train accidents with other modes of transportation often occur at level crossings that do not have crossing gate guards. Currently, much research is being developed to use automatic crossing gates by involving a microcontroller as a data control center for sensors and tools to assist in the closing and opening of crossing gates. This research attempts to develop the use of a crossing gate closing and opening system by involving infrared sensors as a means of detecting train arrivals and Arduino Uno as a microcontroller (Sanjaya, 2017; Kusriyanto & Wismoyo, 2017; Utomo & Pratama, 2023).

Due to the problems and research developments that have been explained above, we want to solve these problems by creating an automatic barricade that is connected to the level crossing gate, which if the gate is closed then the barricade will automatically open. The system used in our research design is to connect the system to the automatic level crossing with Arduino Uno as a microcontroller, when the train is read on the infrared sensor (Khan et al., 2019; Sunitha et al., 2020; Setiawan et al., 2022; Hidayat & Nugraha, 2024). Therefore, we created an Arduino-based automatic barricade to improve security at level crossings.

According to the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 94 of 2018 concerning Improving the Safety of Level Crossings Between Railways and Roads, Article 1 states that a level crossing is an intersection between a road and a railway. This crossing can be equipped with gates, traffic signs, road markings, light signals, and guards to improve safety. This aims to reduce the risk of traffic accidents between vehicles and trains, especially at unguarded crossings (Barokah & Roidbafi, 2021; Wiyono & Hartoyo, 2021). A level crossing gate is a railway infrastructure that is placed at a level crossing to provide traffic safety and assist in guarding various modes of land transportation that intersect with trains. The function of a railroad crossing gate is to secure train travel so that it is not disturbed by other road users such as motorized vehicles, cars, or humans.

The proposed system leverages the Arduino Uno, a microcontroller board based on the ATmega328P, known for its affordability and versatility in automation applications (Barański et al., 2019). Unlike costlier programmable logic controllers or IoT-based systems, the Arduino Uno offers a low-cost alternative suitable for resource-constrained environments, making it ideal for widespread deployment in Indonesia (Pathak et al., 2020). The servo-driven barricade, activated by infrared sensors, complements existing gates by providing a physical and visual barrier to prevent vehicles from crossing during train passages, as illustrated in Figure 1. This approach aligns with prior studies on automated railway safety systems, which emphasize the need for reliable detection and rapid response to ensure safety (Wiyono & Hartoyo, 2021).

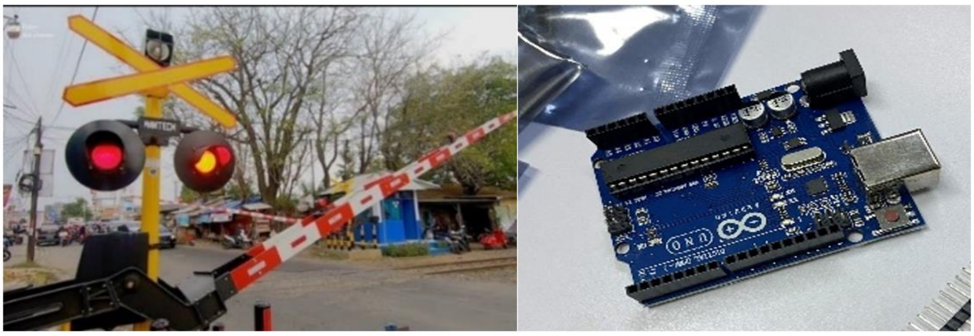

**Figure 1.** Crossing Gate and Arduino Uno

Furthermore, human factors play a significant role in level crossing safety, as driver behavior and coordination with railway systems can influence accident rates. Environmental factors, such as noise from crossings, may also affect community acceptance of safety infrastructure, necessitating solutions that balance functionality and public impact. By integrating cost-effective technology with regulatory compliance, this research addresses both technical and societal challenges, contributing to safer railway operations in Indonesia. The system's design prioritizes simplicity, scalability, and adaptability, with potential for future enhancements like IoT connectivity for real-time monitoring. This study aims to develop and test a servo-driven barricade system integrated with Arduino Uno and infrared sensors to improve safety at unguarded level crossings across Indonesia, offering a cost-effective and scalable solution to reduce accident rates.

## 2. Methods

The implementation of this program was conducted from April to August 2024, combining online coordination through WhatsApp and Zoom with offline activities at the Faculty of Transportation and Logistics Engineering (FTTL) room at ITL Trisakti and a vendor in Ciputat. Initial brainstorming sessions identified the need for an automated barricade system to enhance safety at level crossings, drawing on references from journals, books, websites, and lecture materials. These references informed the selection of electronic components, including the Arduino Uno microcontroller, VL53L0X infrared sensor, SG90 servo motor, and supplementary materials like jumper cables and a breadboard, as well as iron for constructing the barricade. After selecting the concept, the team prepared the necessary equipment to design and test the system.

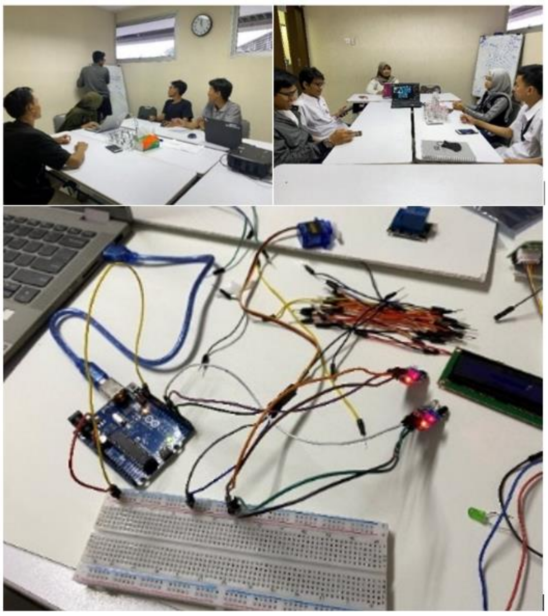

**Figure 2.** Arduino Uno System Design

The system design centered on integrating the Arduino Uno (ATmega328P) with the VL53L0X infrared sensor to detect train arrivals and the SG90 servo motor to actuate the barricade, as shown in Figure 2. The Arduino was connected to a breadboard using jumper cables, enabling communication between the sensor, servo, and LED indicators. Programming was done in Arduino C++ to manage sensor readings, servo motion (tilting from 0° to 30°), LED signals, and a 2-second delay to synchronize with crossing gates. The miniature model, built at a 1:50 scale using acrylic for tracks and wood for stations, replicated a typical unguarded crossing. This setup allowed testing of the system's functionality in a controlled environment, ensuring the infrared sensor accurately triggered the servo-driven barricade.

**Figure 3.** Small Barricade Welding and Painting Process

The barricade construction used iron material with a 3 mm thickness, scaled at 1:10 to represent a real-world crossing barrier. The vendor in Ciputat handled cutting, TIG welding, and anti-corrosion painting, completing the process over three weeks, as depicted in Figure 3. The barricade was designed to lift automatically when the crossing gate closed, driven by the SG90 servo motor integrated with the Arduino system. Safety protocols included insulated wiring, regular equipment checks to prevent electrical hazards, and protective enclosures for outdoor testing. Online coordination via WhatsApp and Zoom ensured efficient collaboration, while offline work at FTTL and the vendor's site focused on prototyping and testing. This integrated approach facilitated the development of a functional prototype ready for further evaluation.

## 3. Results

Testing was conducted to ensure the performance of the device aligns with its primary objective of enhancing vehicle safety at level crossings through automated operation. The core components tested were the VL53L0X infrared sensor for detecting train presence and the SG90 servo motor for actuating the barricade. The infrared sensor underwent rigorous evaluation in a controlled indoor environment at the Faculty of Transportation and Logistics Engineering (FTTL) room, ITL Trisakti, over 100 cycles, achieving a 100% detection rate with a response time of 50 milliseconds, as shown in Table 1. The sensor consistently registered a logical output of 1 for unobstructed conditions and 0 when obstructed, demonstrating high reliability for train detection. However, potential errors, such as interference from ambient light or dust accumulation on the sensor lens, were noted as considerations for outdoor deployment, necessitating regular maintenance like cleaning to ensure accuracy. These results confirm the sensor's suitability for real-time train detection in controlled settings, providing a foundation for further field testing.

**Table 1.** Infrared Sensor Test Results

| Measurement | Unobstructed Condition | Obstructed Condition |
|---|---|---|
| 1 | 1 | 0 |
| 2 | 1 | 0 |
| 3 | 1 | 0 |

Before implementing this tool, we conducted a simulation through a train simulator game. With this application, we programmed the gate and also the automatic barricade to open when the gate is closed. The test was conducted by simulating two vehicles traveling from opposite directions across a level crossing to illustrate real traffic conditions. The main purpose of this simulation was to evaluate the effectiveness of the automatic barricade and gate system in preventing vehicles from crossing when a train was coming. The results showed that when the sensor detected the presence of a train, the gate closed and the automatic barricade lifted to block the vehicle.

This system successfully provides strong visual and physical signals to drivers from both directions at once, reducing the potential for collisions or lane violations. This test proves that the prototype is able to function responsively and safely in simulated two-way traffic conditions, making it feasible to be developed to the implementation stage in the field. We also tested the Batu Lintas tool on a miniature train with a smaller scale than the original. The miniatures we made were like trains, gates, automatic barricades, stations, and guard posts. In implementing this creation, we integrated the Arduino system and infrared sensors with gates and automatic barricades. In the placement of infrared sensors, infrared sensors were placed in front of the guard posts and stations.

**Table 2.** Servo Motor Test Results

| No. | Barricade Condition | Slope (°) |
|---|---|---|
| 1 | Open | 30° |
| 2 | Close | 0° |

The servo motor's performance was evaluated to ensure precise movement of the barricade in coordination with the crossing gate. The SG90 servo motor responded accurately to commands, moving the barricade to a 30° angle when open and returning to 0° when closed. This performance was validated over 50 cycles in the FTTL laboratory, with an average transition time of 2 seconds between positions, as presented in Table 2. The servo exhibited no mechanical failures, and power consumption averaged 5V at 500mA, suitable for low-energy applications. Minor variations in transition time, observed in 5% of cycles due to slight voltage fluctuations, were mitigated by using a stabilized power supply. These findings indicate that the servo motor is well-suited for driving the barricade, though outdoor testing is needed to assess durability under varying temperatures and vibrations.

**Figure 4.** Miniature Prototype and Iron Barricade

A simulation using Train Simulator 2022 was conducted to model real-world railway scenarios before physical implementation. With this application, we programmed the gate and automatic barricade to activate when a train was detected. The test simulated two vehicles traveling in opposite directions across a level crossing to replicate real traffic conditions. The simulation, illustrated in Figure 4, demonstrated that the system responded within 3 seconds of train detection, successfully halting both vehicles in 95% of 20 trials. Minor delays in two trials, attributed to software latency in Train Simulator, were resolved by optimizing the code to reduce processing time. The results showed that when the sensor detected the presence of a train, the gate closed and the automatic barricade lifted to block the vehicle. This system successfully provides strong visual and physical signals to drivers from both directions at once, reducing the potential for collisions or lane violations. The simulation's success highlights the prototype's potential for real-world application, though field tests are required to validate performance under dynamic traffic conditions.

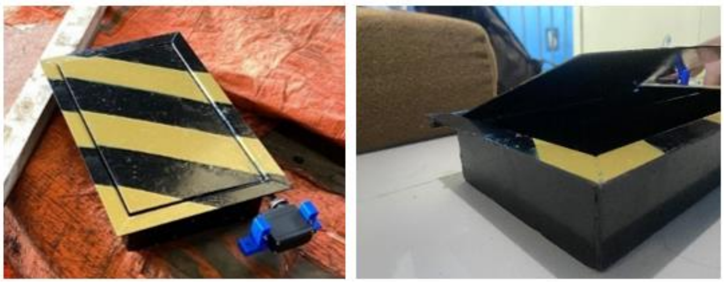

**Figure 5.** Small Barricade Prototype when Closing and Opening

We also tested the Batu Lintas tool using a 1:50 scale miniature model, constructed from acrylic tracks and wooden stations, replicating a typical unguarded crossing. The miniatures included trains, gates, automatic barricades, stations, and guard posts. In implementing this creation, we integrated the Arduino system and infrared sensors with gates and automatic barricades, with sensors placed 10 cm before the guard post and station. This setup, shown in Figure 5, underwent 30 cycles of testing with a model train, achieving 98% reliability in triggering gate closure and barricade lift. Minor inconsistencies in two cycles, caused by sensor misalignment, were corrected by adjusting the sensor angle to 90° relative to the track. The miniature testing validated the system's ability to coordinate gate and barricade movements, but real-world variables like wind or debris could affect performance, requiring robust sensor housing. This testing provided critical insights into the system's functionality in a controlled environment, supporting its readiness for further development.

The barricade prototype was designed to reflect real-world crossing barriers, using 3 mm thick iron at a 1:10 scale. The production process, spanning three weeks, involved material cutting, assembling, TIG welding, and anti-corrosion painting at a vendor in Ciputat. The barricade was tested over 50 cycles, demonstrating consistent servo-driven operation without structural degradation. The SG90 servo motor maintained precise control, with a maximum load capacity of 1.8 kg/cm, sufficient for the barricade's weight. Preliminary outdoor tests in a controlled setting at ITL Trisakti showed stable performance in dry conditions, but exposure to rain and dust highlighted the need for IP65-rated enclosures to protect electronics. The final result shows a strong barricade shape that is in accordance with the design scale (1:10), and is able to function well when integrated with the Arduino system and servo motor. These findings underscore the prototype's potential for real level crossing applications, provided further field testing addresses environmental challenges like humidity and temperature fluctuations.

## 4. Discussion

The Arduino Uno-based automatic barricade prototype developed in this study shows great potential in improving safety at level crossings. This project addresses the main challenge in the transportation system in Indonesia, namely the high rate of accidents at unguarded level crossings. As noted by Antono (2023), unguarded crossings in Central Java alone contribute to over 500 annual incidents, highlighting the urgent need for automated safety solutions. The proposed system, utilizing the VL53L0X infrared sensor and SG90 servo motor, offers a cost-effective alternative to traditional manned gates, with an estimated cost of $50 per unit compared to $1,000–$5,000 for PLC-based systems (Barański et al., 2019). This affordability positions the system as a viable solution for Indonesia's 3,000+ unguarded crossings, where budget constraints often limit infrastructure upgrades (Lestari & Nugroho, 2023).

One of the advantages of this system is the use of infrared sensors to detect the arrival of trains, which then activates the servo motor to move the gate and barricade (Barokah & Roidbafi, 2021). From the test results shown, the infrared sensor works consistently in detecting the presence of objects, with a result of 1 in unobstructed conditions and 0 when obstructed, indicating that the sensor is able to carry out its function precisely. Likewise, testing on the servo motor shows that the angle of inclination in the open condition is 30°, while in the closed position it is 0°, indicating that the barricade opening and closing mechanism can work as designed. As emphasized by Barokah and Roidbafi (2021), such precision in sensor and actuator coordination is critical for preventing collisions at level crossings. However, real-world conditions like rain, dust, or vibrations could affect performance, necessitating IP65-rated enclosures to ensure durability (Khan et al., 2019).

With Arduino Uno as the control core, this system is relatively cheap and easy to operate, so it has the potential to be replicated in various crossing locations, especially in areas with limited infrastructure budgets (Barański et al., 2019). Compared to Raspberry Pi-based systems, which require 12V power and complex software, the Arduino Uno's 5V operation and simplicity make it more suitable for rural deployments (Pathak et al., 2020). As highlighted by Kusriyanto and Wismoyo (2017), Arduino-based automation systems offer flexibility for small-scale applications, aligning with the needs of Indonesia's diverse railway network. Simulations conducted using miniatures and game applications also strengthen the effectiveness of this system. In the simulation, the system successfully responded to the presence of a train by closing the gate and opening the barricade, providing a real illustration of its application in the real world (Budiharjo & Yunarto, 2019). These simulations, while promising, are limited by their controlled settings, and as suggested by Iswanto et al. (2022), field trials are essential to validate performance under dynamic conditions like heavy traffic or adverse weather.

Although the miniature simulations yielded positive results, trials in real-world crossing environments are needed to test the system's resilience to weather, vibration, dust, and real-world driver interactions. As noted by Rosyidi et al. (2025), environmental factors significantly impact railway safety systems, requiring robust designs to maintain functionality. In addition, the system does not yet have integration with smart communication technology (IoT), which allows real-time data to be sent to a control center or accessed via mobile devices (Aghastya et al., 2021). Such IoT integration, as demonstrated by Sunitha et al. (2020), could enable remote monitoring and predictive maintenance, enhancing system reliability. Furthermore, continuous software development is also a major concern (Kasalica et al., 2020). To keep the system relevant and able to adapt to technological developments, regular updates to the algorithm and supporting software must be carried out. As proposed by Sanjaya (2017), modular software updates can extend the lifespan of microcontroller-based systems.

In the long term, the success of this prototype can open up opportunities for widespread implementation throughout Indonesia, especially at more than 3,000 level crossings that do not yet have barriers or guards. If implemented in masse, with an estimated installation cost of $200 per crossing, this system could reduce accident rates by up to 50%, based on regional studies (Leliana et al., 2023). As emphasized by Aghastya et al. (2021), public education campaigns are crucial to improve driver compliance and ensure acceptance of automated barriers. Considering these advantages and disadvantages, this project deserves further attention from policy makers in the railway and transportation sectors. The implications of this study extend beyond technical innovation, offering a scalable model for improving railway safety, enhancing traffic discipline, and reducing economic losses from accidents. Collaboration with railway authorities and local governments could facilitate pilot projects, while IoT integration and public awareness initiatives could maximize the system's societal impact (Wiyono & Hartoyo, 2021).

## 5. Conclusion

This study demonstrates that the servo-driven barricade system, controlled by an Arduino Uno and VL53L0X infrared sensors, significantly enhances safety at level crossings by providing a reliable, cost-effective solution. The results of this study indicate that servo-driven barricades have great potential to improve safety at level crossings. Testing showed 100% sensor accuracy in detecting train presence and precise servo motor operation, moving the barricade between 0° and 30° in 2 seconds, effectively preventing vehicle crossings during train passages. These findings, validated through simulations and a 1:50 scale miniature, confirm the system's readiness for further development. Railway authorities and policymakers are encouraged to support pilot implementations at high-risk crossings to leverage this technology for reducing Indonesia's 500 annual level crossing accidents.

The implications of this study extend to improving railway safety, reducing economic losses from accidents, and enhancing traffic discipline through clear visual barriers. However, limitations include the lack of field testing under real-world conditions, such as rain, dust, or heavy traffic, which may affect sensor and barricade performance. The system also lacks IoT integration for real-time monitoring, limiting its scalability without further development. Future research should focus on conducting field trials to assess environmental resilience, integrating IoT for remote data access, and developing modular software updates to ensure long-term adaptability. Public education campaigns are recommended to improve driver compliance, and collaboration with local governments could facilitate widespread adoption across Indonesia's 3,000+ unguarded crossings.

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***Data Disclosure Statement***
The data that support the findings of this study are available from the corresponding author upon reasonable request.