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SMART BRIDGE COLLAPSE PREVENTION SYSTEM

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ABSTRACT
In densely populated areas, pedestrian bridges play a crucial role in alleviating automobile congestion. However, the intermittent collapse of these bridges is a severe concern. These mishaps result in financial, resource, and human losses. Numerous research has been done to address this issue. Sensors have been widely used to monitor this condition. These sensors are linked to microcontroller monitoring units that analyze real-time data on load, stresses, and other attributes to ensure bridge structural integrity. Trailblazing algorithms are useful for analyzing structural defaults in detail, as stated in literature. This article examines the implementation of a Smart Pedestrian Bridge Collapse Prevention system to improve safety measures and prevent damage to important urban assets. The implementation of such a system involves a multifaceted approach, combining advanced sensor technology, robust data analysis algorithms, and real-time monitoring capabilities. Through seamless integration with existing infrastructure and proactive maintenance protocols, the system aims to mitigate the risks associated with bridge collapses and ensure the uninterrupted functionality of pedestrian thoroughfares in urban landscapes. Furthermore, by leveraging insights gleaned from data analytics and predictive modeling, authorities can make informed decisions regarding maintenance schedules, structural upgrades, and emergency response plans. In essence, the Smart Pedestrian Bridge Collapse Prevention system represents a proactive and technology-driven approach to address a longstanding challenge in urban infrastructure management.

Keywords: Pedestrian bridges, structural collapse, electronic sensors, microcontroller monitoring units

I. INTRODUCTION

1.1 SMART BRIDGE

A smart bridge utilizes sensors and data to enhance the efficiency and safety of bikers and pedestrians. The bridge may collect information about traffic flow, weather, and air quality. This data can inform changes to the bridge's lighting, signage, and other elements, enhancing user safety and comfort.
Smart bridges can increase efficiency and safety while simultaneously collecting data on bicycles and pedestrians' actions. This data can help improve the efficiency and safety of current transportation infrastructure when planning for future improvements. The bridge's sensors can identify cyclists and humans and alter lighting and signs accordingly. Lights can be muted or brightened depending on traffic or fog conditions. The placard can warn pedestrians about potential hazards like ice weather
The concept of using lasers and sensors to count the number of individuals entering a bridge represents a proactive approach to mitigate the risk of collapse by regulating pedestrian traffic. By accurately tracking

the influx of pedestrians, this innovative system can effectively manage crowd density and prevent overcrowding, which is frequently cited as a primary cause of pedestrian bridge failures.
Central to this concept is the establishment of an optimal threshold for the number of individuals allowed on the bridge simultaneously, typically set to align with the bridge's designed capacity. Through continuous monitoring and real-time data analysis, the system dynamically adjusts this threshold to ensure that the number of people on the bridge remains within safe limits.
In practical terms, as pedestrians enter the bridge, the laser-based sensors detect their presence and transmit this information to a centralized monitoring unit. By comparing the current pedestrian count with the predefined safe capacity threshold, the system can trigger alerts or take proactive measures to regulate pedestrian flow if the threshold is exceeded.
Such measures may include displaying real-time occupancy information at bridge entrances to inform pedestrians, implementing traffic control mechanisms such as turnstiles or gates to limit access when capacity is reached, or even coordinating with local authorities to divert pedestrian traffic to alternative routes if necessary. Figure 1 illustrates the representation of the proposed system for smart bridge.

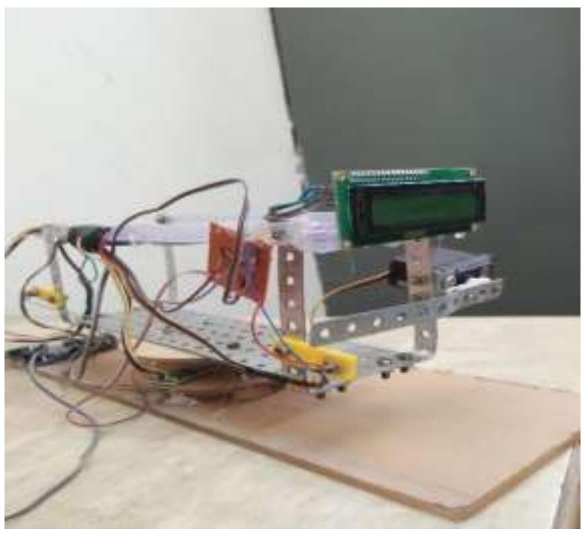

Figure 1: Representation of the proposed system for Smart Bridge

By actively managing pedestrian density, this smart structure not only reduces the risk of structural overload and potential collapse but also enhances overall safety and user experience. Moreover, by preventing overcrowding incidents, the system contributes to the longevity and reliability of pedestrian bridges, safeguarding critical urban infrastructure and minimizing disruptions to transportation networks.

II Literature

In the paper [1] presented by S. Joshi, N. Naga, et al. presented at IABMAS 2018 in Melbourne, Australia proposed a new approach. The information currently available is insufficient for repairing and renovating bridges, highlighting the urgent need for skilled laborers capable of swiftly addressing these issues. The financial requirement is significant, and there is a lack of trained personnel to undertake such large-scale tasks. Prior to the implementation of the Indian Bridge Management System (IBMS), the Digital Inventory of Structures (Bridges & Culverts) lacked practicality, especially due to the absence of comprehensive historical data on inspections and maintenance activities. It is evident that regular maintenance is crucial to ensuring the long-term usability of infrastructure. Neglecting routine upkeep renders the considerable investment in infrastructure construction futile. Access to relevant data and analytical tools is essential for informed and timely interventions.

In the paper [2] presented at IABMAS 2018 in Melbourne, Australia, presented by S. Joshi and S. S. Raju proposed a new approach. The Indian Bridge Management System (IBMS) was launched by the Ministry of Road Transport and Highways, Government of India, in September 2015. Introducing IBMS within a short timeframe in a country lacking a comprehensive bridge management system was a monumental task. The practicality of implementation formed the basis for initial development efforts. Key criteria were established to define bridges and ensure adequate data collection for digitizing the management system. Following the launch of the Inventory and Inspection module in October 2015, a series of bridges underwent inventorying and examination cycles.

In the paper [3] by S. A. Faroz and S. Ghosh, a novel approach is proposed. The primary mechanism through which corrosion impacts reinforced concrete (RC) bridges is by diminishing the volume of steel reinforcement. Traditional theoretical models for predicting this corrosion-induced steel loss often fail to accurately reflect real-world corrosion scenarios. An alternative method for assessing the current condition of a structure involves non-destructive testing/evaluation (NDT/E) or monitoring. However, neither method alone provides a comprehensive understanding of a bridge's deterioration over time. To effectively manage the degradation of a bridge throughout its lifespan, it is beneficial to integrate the predictive capabilities of theoretical degradation models with NDT/E data in a systematic manner.
To address uncertainties inherent in both the physical corrosion process and the corrosion growth models used for prediction, a sequential Bayesian updating approach is employed. Stochastic parameters are employed to characterize the modified corrosion growth model. By considering these parameter uncertainties, a robust estimation of time-varying steel loss due to corrosion is achieved. The modified model is then applied to evaluate the reliability of an RC bridge slab undergoing corrosion. The service life of the bridge is determined by considering flexural failure and the desired level of reliability.

In the paper [4] by R. A. Rogers, M. Al-Ani et al, presented in the Technical report, NZTA research report 502 in Wellington, New Zealand in 2013, a novel approach is proposed. Many older bridges exhibit outdated designs in terms of longevity and possess certain characteristics that increase susceptibility to corrosion of the pre-tensioned reinforcement. Addressing corrosion in pre-tensioned reinforcement poses significant challenges, often requiring the replacement of the entire bridge superstructure due to difficulties in halting corrosion and assessing and restoring structural integrity.
Recent research indicates that despite passing routine inspections without apparent issues, many pre-tensioned concrete bridge structures in New Zealand may already be experiencing significant deterioration. The centralized control over bridge design by various government agencies over time has led to efficiencies in the bridge construction industry but has also resulted in similar design traits being prevalent in bridges constructed during specific periods. Therefore, historical design documents offer valuable insights into design characteristics likely present in bridges built during the document's validity period.

In the paper [5] presented in September 2009, Andrew Gastineau, Tyler Johnson, and Arturo Schultz proposed a comprehensive framework. Following the collapse of the I-35W bridge in August 2007, there has been considerable interest in bridge health monitoring. This study provides an extensive lexicon of available monitoring systems and defines terms related to bridge health monitoring. The glossary aims to

enhance readers' understanding of the strengths and weaknesses of different systems, empowering them to make informed decisions.
The authors conducted a survey targeting for-profit businesses offering surveillance technology. Out of 72 questionnaires distributed, 38 commercial companies responded, and their insights are incorporated into the report. These surveys provide valuable information for summarizing the current commercial systems available.
To assist bridge owners in streamlining their selection process for suitable companies, criteria for system evaluation were established. By answering a series of questions about their specific bridge, owners can utilize Microsoft Excel software to determine the optimal solution for their scenario. An illustrative example is provided to clarify the program's functionality. Additional criteria were also developed to aid in the final product selection once the list of potential companies was narrowed down.

In the paper [6] published in Reliability Engineering and System Safety in 2008, P. S. Marsh and D. M. Frangopol proposed an innovative approach. The rate of corrosion of reinforcing steel significantly influences the reliability of RC bridge decks. Structural health monitoring (SHM) methods, such as embedded corrosion rate sensors, can greatly improve the quantification of steel corrosion rates, leading to more accurate estimations of structural safety and serviceability.
Due to uncertainties in climatic conditions, concrete properties, and other factors, the corrosion rate of reinforcing steel can vary significantly within a specific structural component and over time. To better predict these temporal and spatial variations, multiple corrosion rate sensors can be strategically placed across a structural component, such as a bridge deck.
The authors employed Monte Carlo simulation and a computational reliability model to achieve this objective. They utilized empirical spatial and temporal correlations to estimate corrosion rate sensor data for various critical sections of an RC bridge deck. Subsequently, an existing reliability model, which did not account for spatial variability, was enhanced using this data.
The improved reliability model integrates temporal and spatial fluctuations in corrosion rate data, providing a more accurate estimation of the service life of an RC bridge deck slab.

In the paper [7] published in the International Journal of Research Publication and Reviews in 2023, Prof. Nandini Kad, Pratik Thorat et al. proposed an innovative solution for managing hanging bridges to prevent collapses caused by overcrowding.

The "SMART BRIDGE OF MORBI" was constructed with a designated capacity in mind, which restricts the number of people allowed to cross it, thus highlighting its importance. This bridge stands out as a pioneer due to its unique feature. Bridge sensors are designed to monitor the load on the bridge, detecting when it approaches its capacity limit. Upon reaching an overload condition, barricades are automatically closed. Moreover, the sensors detect when individuals leave the bridge, promptly reopening the gate to maintain compliance with the bridge's capacity.

The system integrates the Arduino UNO microcontroller with both sensors and an LCD display. The Flex sensor is utilized to measure the bridge's tilt angle and detect cracks, triggering an alert if predefined thresholds are exceeded. Placed beneath the bridge and within gaps, the water level sensor alerts the Arduino UNO when water reaches it, activating an alarm. An LCD display is incorporated to visually indicate any detected faults with a "DANGER" message. To control access to the bridge, servo motors are used to close the roads leading to it. A buzzer is employed to audibly signal alerts in case of danger.

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Data transmission to the server is facilitated by a Wi-Fi modem, utilizing “THINGSPEAK” for visualizing sensor readings in this study.

III. METHODOLOGY AND DISCUSION

The system would be made up of various interconnected components that would allow the pedestrian bridge control mechanism to function more efficiently. LASER1 is located at the center of the system and emits a beam that is detected by a photodiode. When this beam is disrupted by someone crossing the bridge, the photodiode transmits a signal to a driving circuit, which tallies the number of disruptions, thereby counting the number of individuals who enter the bridge. When an interruption is detected, a servo motor is activated to open the entry and allow access to the bridge.
Figure 2 assembles the working procedure of entire smart bridge system

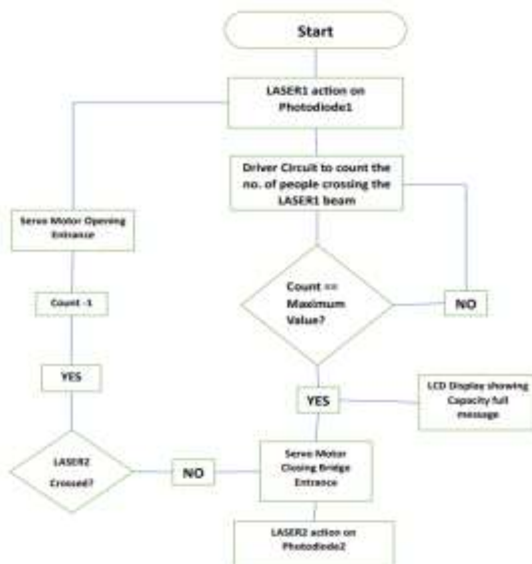

Figure 2: Flow chart proposing the workflow for the Smart Bridge

The system determines whether the count has reached its maximum value, which indicates that the bridge has surpassed its capacity. If this occurs, an LCD display module displays a "Capacity Full" message, indicating that no additional additions are permitted. If the count has not yet reached the maximum amount, the algorithm subtracts one to accommodate the person who has just crossed, and the cycle begins with LASER1. Meanwhile, the system continuously scans LASER2 to detect anybody leaving the bridge. When LASER2 is halted, signaling someone's departure, a servo motor is engaged once more, this time to close the bridge door. Finally, the procedure is repeated, with LASER2 and Photodiode2 overseeing the exit process, assuring smooth and controlled pedestrian flow across the bridge.

IV. HARDWARE DESCRIPTION

The proposed system requires following hardware components:

4.1 Laser

The laser, in conjunction with the photodiode, acts as a precise and dependable trigger mechanism to initiate the pedestrian bridge system's counting function. The laser beam, positioned at the bridge's entrance, forms an invisible line that serves as a detecting border. Figure 2 illustrates a typical LASER diode.

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Figure 2: LASER Diode

4.2 Photodiode

Photodiodes can detect the presence of a person or object by sensing changes in ambient light. When someone enters a space monitored by the photodiode, they interrupt the light path, causing a decrease in the amount of light reaching the photodiode. This change is detected as a drop in current output, triggering the system to respond accordingly. Figure 3 shows a typically used photodiode so used in this system.

Figure 3: Photodiode

4.3 BMP Sensor

The BMP Sensor is the pressure monitoring instrument. When individuals enter a bridge, the pressure from their weight generates an electrical signal (voltage). Figure 4 provides an illustration of the BMP sensor.

Figure 4: BMP Sensor

4.4 Servo Motor

The main output device that is driven by the driver circuit is this motor that is fastened to the tollgates. Compact, lightweight, and capable of strong output. Servos are smaller than conventional types and can rotate up to 180 degrees, but they nonetheless perform similarly. Figure 5 provides an illustration of the servo motor.

Figure 5: Servo Motor

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4.5 Arduino Uno

The fundamental component of this design's driving circuit is the Arduino Uno. User-friendly hardware and software form the foundation of the open-source Arduino Uno electronics platform. In line with the provided program for operating tollgates, the Arduino microcontroller is set up to accept data from the Laser and Photodiode setup and deliver commands to the relevant output devices. Figure 6 gives an illustration of the Arduino UNO microcontroller.

Figure 6: Arduino UNO

4.6 NPN Transistor

This NPN silicon epitaxial transistor is designed for linear and switching applications. Its three pins are input, output, and ground. This circuit design uses an NPN transistor to provide switching. The changes made to the power levels will be reflected in the signal sent to the primary output device. Figure 7 gives an illustration of the NPN Transistor.

Figure 7: NPN Transistor

4.7 LCD Display

It is beneficial for administration and displays the data that is gathered by all the programs and sensors. It is one of the outputs of the overall circuitry for the project. The driving circuit will transmit to the LCD display the number of people using the bridge as well as a message that the number of people using it has exceeded its maximum. Figure 8 provides an illustration of a typical 16x2 LCD Display.

Figure 8: 16x2 LCD Display

V Functioning of System

The smart pedestrian bridge system includes a variety of sensors and components to effectively manage pedestrian traffic.

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Using Arduino UNO microcontroller to write the driver logic to run the whole system, and LASER and Photodiode as main unit behind counting the number of people entering the bridge, servo motor and LCD display used as output devices, the architecture is as illustrated in the Figure 9 where:

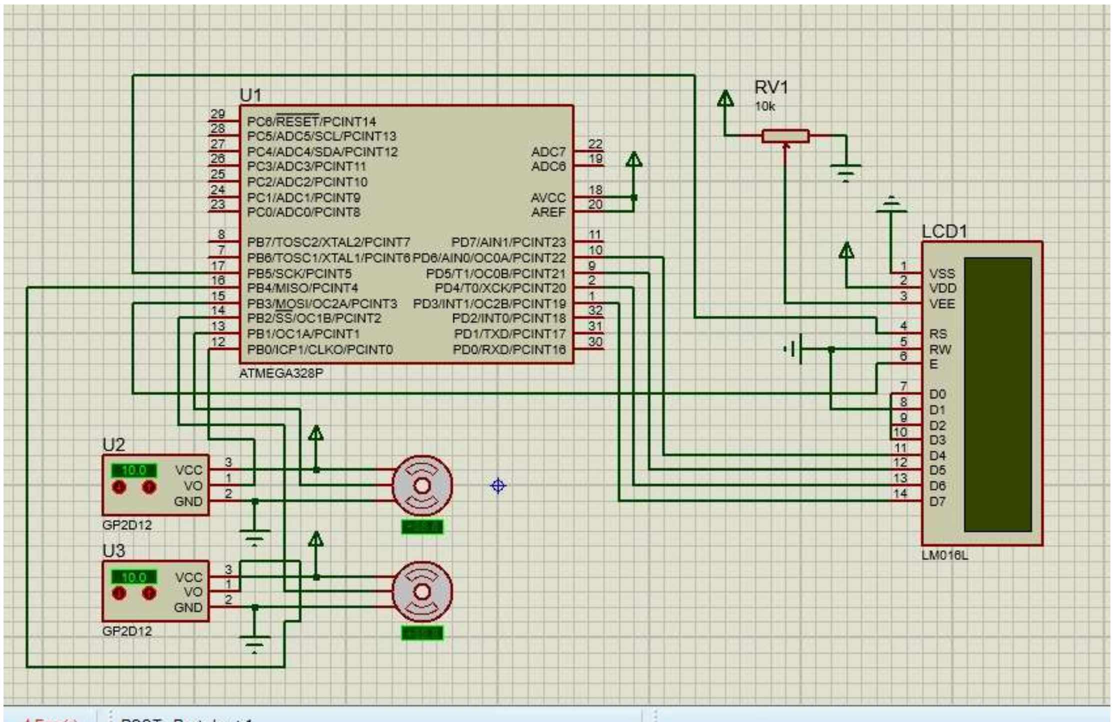

Figure 9: Architecture of Smart Bridge

1. At the bridge's entry, a laser and photodiode system create an invisible line that serves as a trigger. When individuals cross this line, the laser recognizes their presence and starts the counting process.
2. Ultrasonic sensors also monitor traffic flow, safety conditions, structural integrity, and environmental elements in real time, giving full monitoring.
3. As pedestrians cross the bridge, the BMP sensor detects the pressure caused by their weight and converts it into an electrical signal. This data, together with inputs from other sensors, is processed by the Arduino Uno microcontroller, which subsequently directs appropriate output devices such as servo motors coupled to toll gates.
4. Furthermore, the NPN transistor is an important component for switching in circuit design, allowing modifications to power levels dependent on sensor inputs.
5. The LCD panel serves as a user-friendly interface, giving administrators with real-time information about pedestrian traffic and system status. In the event of congestion, the display will inform authorities by displaying that the bridge's maximum capacity has been surpassed.
6. Overall, the smart pedestrian bridge system assures effective pedestrian management by seamlessly integrating sensors, microcontrollers, and output devices, while also improving user safety and convenience.

VI RESULT AND DISCUSSION

6.1 Basic understanding for Finding Results

This bridge system is basically working on two principles:

1. Counting the number of people entering the bridge with the help of LASER Photodiode setup available at the entrance of bridge.
2. Measuring the load on the bridge and acting by comparing the load with bridge capacity.

For this purpose, a load sensor (BMP sensor) is connected to the bridge. The load sensor is used such that its capacity is equivalent to the actual capacity of the bridge.

The opening and closing of the bridge gates will be decided by a factor termed as CLOSING RATIO (CR) which is defined as the ratio of total load over the bridge to the capacity of the bridge (capacity of BMP sensor).

The gates of bridge work as per the following nature of CR:

1. The gates of bridge will remain open if the value of CR is less than 1, which means that the bridge will remain open till maximum allowed capacity is not reached.
2. The gates of bridge will close immediately if the value of CR becomes greater than or equal to 1, which means that either maximum allowed capacity is reached or exceeded.

6.2 Result

In the system designed for this research (Figure 1), we have used the BMP sensor having capacity of 5Kg and we used dummy objects as the subjects for the testing of the proposed system.

The results thus obtained in this process are as mentioned in the Table 1.

Sr. No.	Count	Load on Bridge	CR	Status of Bridge
1.	50	5.10Kg	1.020	Entrance Closed
2.	49	5.05Kg	1.010	Entrance Closed
3.	47	5.11Kg	1.022	Entrance Closed
4.	51	5.00Kg	5.000	Entrance Closed
5.	53	5.02Kg	1.004	Entrance Closed
6.	55	5.12Kg	1.024	Entrance Closed
7.	45	5.06Kg	1.012	Entrance Closed
8.	51	5.09Kg	1.018	Entrance Closed
9.	55	5.15Kg	1.030	Entrance Closed
10.	41	5.01Kg	1.002	Entrance Closed

Table 1: Tabular representation of the results of the proposed system

VII. CONCLUSIONS

Based on the results given by the system, following conclusions can be drawn:

1. It is difficult to design a safe bridge management system based on counting the number of people entering the bridge as the people vary in physical appearance, not all people weigh same.
2. A bridge collapse prevention system based on the load sensors which have the capacity equivalent to the actual capacity of the bridge can significantly solve the problem of bridge collapse.
3. Decreasing the number of people over the bridge significantly means reducing the load over the bridge.

The use of sensor-based technology to improve bridge operation and enable the provision of a safe transportation option across the bridges,

VIII. FUTURE WORK

Here is a detailed exploration of the potential future directions for smart bridges:

1. Advanced Sensing Technologies: Future smart bridges will likely incorporate more sophisticated sensing technologies capable of monitoring a broader range of parameters. This could include advanced sensors for detecting structural health, such as distributed fiber optic sensors, wireless strain gauges, and embedded microelectromechanical systems (MEMS). Additionally, environmental sensors may be integrated to monitor factors like temperature, humidity, and corrosion levels, providing comprehensive real-time data for predictive maintenance and early warning systems.
2. Structural Health Monitoring (SHM) Systems: SHM systems will evolve to provide more comprehensive and accurate assessments of bridge condition and performance. Future SHM technologies may incorporate advanced imaging techniques such as LiDAR (Light Detection and Ranging) and advanced non-destructive testing methods to evaluate structural integrity, detect defects, and assess the impact of environmental factors over time.
3. Smart Materials and Structural Design: Advancements in material science and structural engineering will lead to the development of smart materials and innovative design concepts for bridges. Self-healing materials, shape memory alloys, and carbon nanotube composites may be utilized to enhance durability, resilience, and longevity while reducing maintenance requirements and life-cycle costs. Additionally, novel structural configurations, such as deployable and adaptive structures, may be explored to improve flexibility, adaptability, and performance under dynamic loading conditions.
4. Energy Harvesting and Sustainability: Smart bridges of the future may incorporate energy harvesting technologies to generate power from ambient sources such as vibrations, traffic flow, and solar radiation. This harvested energy can be utilized to power sensors, communication systems, and lighting, reducing reliance on external power sources and enhancing sustainability. Furthermore, smart bridges may integrate green infrastructure elements such as vegetated roofs, rainwater harvesting systems, and wildlife habitats to promote environmental conservation and ecological resilience.
5. Integrated Transportation Systems: Smart bridges will increasingly be integrated into larger transportation networks and smart city ecosystems. Collaborative frameworks, interoperable data standards, and real-time communication protocols will enable seamless integration between bridges, roads, traffic management systems, public transportation networks, and other urban infrastructure components. This holistic approach to transportation planning and management will optimize traffic flow, reduce congestion, improve safety, and enhance overall urban mobility.
6. Resilience to Climate Change and Natural Disasters: With the increasing frequency and intensity of extreme weather events due to climate change, future smart bridges will be designed and engineered to withstand a broader range of environmental hazards. Climate-resilient materials, innovative structural configurations, and adaptive design strategies will be employed to mitigate the impacts of floods, storms, earthquakes, and other natural disasters.

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