Journal of Research Administration
Society of Research Administrators International

AN INTELLIGENT WEIGHING SYSTEM FOR CONSTRUCTION SITE MATERIAL MANAGEMENT BASED ON VEHICLE IDENTIFICATION AND LOAD VERIFICATION

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Abstract

This paper presents an intelligent weighing system for construction site material management that integrates vehicle identification, load verification, and image-based material category verification. The system aims to address the challenges associated with traditional manual weighing methods and improve the accuracy, efficiency, and security of material delivery tracking. The proposed system architecture includes a vehicle identification module using license plate recognition, a weighbridge control module for capturing gross and tare weights, and an image-based material category verification module. The system is integrated with gate control and warning systems to ensure secure access and real-time alerts. The research findings demonstrate the effectiveness of the system in enhancing the accuracy and reliability of the weighing process, reducing errors, and streamlining material management operations. The adoption of such advanced technologies can significantly improve the productivity, quality, and profitability of construction projects. The paper also discusses the implications for construction material management practices and provides recommendations for system adoption and improvement.

Keywords: Intelligent Weighing System; Construction Material Management; Construction Automation; Supply Chain Management.

1. INTRODUCTION

The construction industry plays a vital role in global economic development but faces challenges in efficiency, productivity, and cost control, particularly in material management [1]. This encompasses the procurement, storage, handling, and use of construction materials [2]. Poor material management practices can cause delays, increased costs, and quality issues that negatively affect project success [3].

Accurate material weighing and verification are crucial for effective management, ensuring that project specifications are met and disputes are minimized [4]. Precise data supports inventory control, cost tracking, and waste reduction [5], whereas errors in weighing can lead to financial losses, project delays, and legal complications [6]. Traditional manual weighing, typically done via weighbridge, is plagued by human error, such as incorrect data entry and inconsistent readings [7]. It also causes bottlenecks, increasing costs [8], and is prone to fraud involving weighbridge operators [9].

To address these challenges, this paper introduces an intelligent weighing system incorporating vehicle identification and load verification. The system aims to automate the weighing process, reducing human intervention, and incorporates image-based categorization for accurate load verification. The research assesses its performance against traditional weighing in efficiency, accuracy, and cost-effectiveness.

The remainder of this paper is structured as follows: Section 2 presents a literature review of current practices and technologies in construction material weighing, automation in logistics, vehicle identification technologies, and the integration of weighing systems with enterprise information systems. Section 3 describes the methodology, including the system architecture, vehicle identification module, material information database, weighbridge control module, image-based material category verification, and integration with gate control and warning systems. Section 4 details the system implementation, covering hardware setup, software development, database design, and user interface. Finally, Section 5 concludes the paper by summarizing the research findings, discussing the implications for construction material management practices, and providing recommendations for system adoption and improvement.

2. LITERATURE REVIEW

2.1 Current practices and technologies used in construction material weighing

Construction material weighing is a crucial process in ensuring the accuracy and efficiency of material management on construction sites. Traditional weighing methods involve the use of manual weighbridges, which require human operators to record the weight of incoming and outgoing vehicles [10]. However, these manual methods are prone to errors and can be time-consuming, leading to delays in material delivery and inventory management [11]. To address these issues, various technologies have been developed and implemented in the construction industry, such as load cell-based weighing systems, which provide more accurate and reliable weight measurements [12]. Additionally, the integration of weighing systems with computer-based data management tools has enabled the automation of weight recording and data analysis processes [13].

2.2 Automation and information technology applications in logistics and material handling

The application of automation and information technology in logistics and material handling has been extensively studied in recent years. Automated material handling systems, such as conveyor belts, automated guided vehicles (AGVs), and robotic arms, have been shown to improve the efficiency and accuracy of material movement in various industries [14]. In the construction industry, the use of radio-frequency identification (RFID) technology has gained popularity for tracking and managing construction materials [15]. RFID tags attached to materials enable real-time monitoring of their location and movement, facilitating better inventory control and reducing the risk of material loss or theft 16]. Moreover, the integration of RFID technology with building information modeling (BIM) has been explored to enhance the visualization and analysis of material flows on construction sites [17].

Table 1. Comparison of automation and information technology applications in logistics and material handling

Technology	Application	Benefits	Limitations
Automated Material Handling Systems (Conveyor belts, AGVs, Robotic arms)	Improve efficiency and accuracy of material movement	- Increased productivity - Reduced labor costs - Enhanced safety	- High initial investment - Requires specialized maintenance and support
Radio-Frequency Identification (RFID)	Track and manage construction materials	- Real-time monitoring of material location and movement - Better inventory contro - Reduced risk of material loss or theft	- Interference from metal and moisture - High cost of tags and readers - Requires specialized software for data management
Building Information Modeling (BIM) Integration	Enhance visualization and analysis of material flows on construction sites	- Improved coordination among project stakeholders - Better planning and decision-making - Increased efficiency and productivity	- Requires high level of detail and accuracy in BIM models - Interoperability issues between different software platforms - Need for specialized training and expertise

The table above compares three key automation and information technology applications in logistics and material handling: automated material handling systems, radio-frequency identification (RFID), and building information modeling (BIM) integration. Each technology has its specific applications, benefits, and limitations.

Automated material handling systems, such as conveyor belts, AGVs, and robotic arms, are used to improve the efficiency and accuracy of material movement. These systems offer increased productivity, reduced labor costs, and enhanced safety. However, they require a high initial investment and specialized maintenance and support.

RFID technology is used for tracking and managing construction materials. It enables real-time monitoring of material location and movement, better inventory control, and reduced risk of material loss or theft. However, RFID systems can be affected by interference from metal and moisture, have a high cost of tags and readers, and require specialized software for data management.

BIM integration enhances the visualization and analysis of material flows on construction sites. It improves coordination among project stakeholders, enables better planning and decision-making, and increases efficiency and productivity. However, BIM integration requires a high level of detail and accuracy in BIM models, may face interoperability issues between different software platforms, and necessitates specialized training and expertise.

Each technology has its strengths and weaknesses, and the choice of technology depends on the specific requirements and constraints of the construction project. A combination of these technologies can be used to optimize logistics and material handling processes in the construction industry.

2.3 Vehicle identification technologies

Vehicle identification technologies play a crucial role in automating the weighing process and improving the accuracy of material delivery verification. License plate recognition (LPR) is a widely used technology for identifying vehicles based on their license plate numbers. LPR systems use cameras and image processing algorithms to capture and analyze license plate images, enabling the automatic recording of vehicle information. In the construction industry, LPR technology has been applied to automate the entry and exit of vehicles at construction sites, as well as to monitor the movement of materials and equipment. Another emerging technology for vehicle identification is radio-frequency identification (RFID), which uses RFID tags attached to vehicles to transmit their unique identification information to readers. RFID technology has been shown to provide a more reliable and efficient means of vehicle identification compared to traditional manual methods.

2.4 Integrating weighing systems with enterprise information systems

The integration of weighing systems with enterprise information systems (EIS) is essential for enabling seamless data exchange and facilitating informed decision-making in construction material management. EIS, such as enterprise resource planning (ERP) and supply chain management (SCM) systems, provide a centralized platform for managing and analyzing data from various sources, including weighing systems. By integrating weighing systems with EIS, construction companies can automate the updating of material inventory levels, track material consumption rates, and generate accurate reports for cost control and billing purposes. Moreover, the integration of weighing data with BIM can enable the visualization of material quantities and locations within the digital model of the construction project, facilitating better planning and coordination among project stakeholders.

3. METHODOLOGY

3.1 System architecture of proposed intelligent weighing system

The proposed intelligent weighing system for construction site material management is designed to automate the weighing process, improve accuracy, and streamline the overall material delivery and verification process. The system architecture consists of several key components that work together to achieve these objectives, as shown in Figure 1.

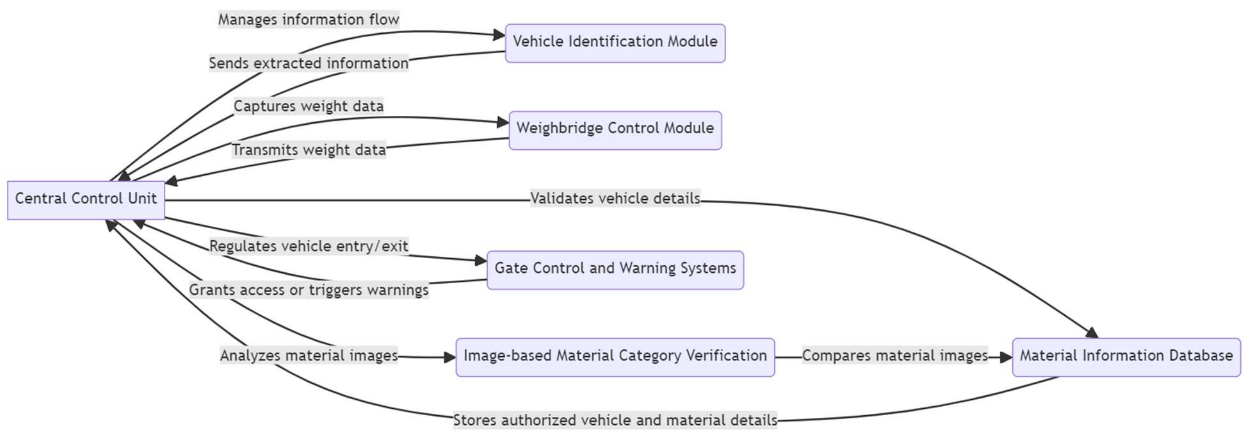

Figure 1: The system architecture

The proposed intelligent weighing system is centered on a control unit that coordinates subsystems and manages data. This unit processes information from the vehicle identification module, which uses license plate recognition (LPR) technology to detect incoming and outgoing vehicles. License plate images are captured and sent to the control unit for validation against a material information database. This database holds details about authorized vehicles, expected material types, and weight ranges, ensuring that incoming vehicles are legitimate and that delivered materials meet project specifications.

The weighbridge control module captures the gross and tare weights of vehicles via the physical weighbridge, transmitting this data to the control unit for analysis. Additionally, the system employs an image-based verification module that uses computer vision to categorize delivered materials, comparing them against the expected categories in the database. This extra validation step reduces discrepancies and ensures accurate material delivery.

Vehicle entry and exit are regulated through gate control and warning systems. Once verification is complete, the control unit either grants access or triggers alerts for discrepancies or unauthorized vehicles, ensuring timely intervention by relevant personnel.

3.2 Vehicle identification module using license plate recognition

The vehicle identification module is a crucial part of the intelligent weighing system, responsible for automatically recognizing and validating vehicles entering and leaving the construction site. It employs license plate recognition (LPR) technology to capture and process vehicle license plate images for verification against the authorized vehicle database.

The LPR process involves image acquisition, pre-processing, plate localization, character segmentation, and recognition. A high-resolution camera positioned at the site’s entry and exit points captures clear license plate images. Pre-processing techniques like noise reduction and contrast enhancement improve image quality and readability. After localizing the plate region, character segmentation algorithms isolate each character, which is then recognized through optical character recognition (OCR) and converted into machine-readable text.

The recognized license plate information is sent to the central control unit to check against the authorized vehicle database. The system automatically verifies the vehicle's legitimacy, granting or denying access based on the database. Additionally, the LPR module tracks and records vehicle movements within the construction site by logging entry and exit times, weighbridge measurements, and unloading activities.

Integrating this module with the intelligent weighing system improves efficiency and accuracy in vehicle identification and access control. By automating these tasks, the system reduces manual interventions, minimizes errors, and optimizes the material delivery workflow.

3.3 Material information database with authorized vehicle and target weight data

The material information database is central to the intelligent weighing system, providing critical data to validate incoming vehicles, verify material categories, and ensure delivered loads meet specified weight requirements.

A primary element is the authorized vehicle list, detailing vehicles allowed on-site for material delivery. This list includes registration numbers, associated suppliers or contractors, permitted material types, and specific access restrictions or permissions. Keeping this list updated helps the system efficiently identify legitimate vehicles and prevent unauthorized access.

The database also stores target weight data, derived from purchase orders, contracts, or requisitions. This data includes expected material types, ordered quantities, and acceptable weight ranges. When a vehicle arrives, the system retrieves the appropriate target weight data based on vehicle and material type, using it as a reference to compare with the weighbridge measurements. If the actual weight falls within the acceptable range, the delivery proceeds; if not, the system flags it for further inspection or rejection.

The database is integral to image-based material category verification, holding visual references for expected materials that aid image recognition algorithms in accurately classifying delivered materials. By comparing captured images against these references, the system confirms correct material delivery or alerts personnel to discrepancies.

Ensuring database reliability requires consistent updates, synchronization with procurement and scheduling systems, and secure access controls to prevent unauthorized modifications. A user-friendly interface allows authorized personnel to input, update, and retrieve information easily.

Integrating this database with other system modules ensures a seamless flow of information, reducing errors, enhancing transparency, and improving decision-making in construction site material management.

3.4 Weighbridge control module for capturing gross and tare weights

The weighbridge control module is responsible for capturing accurate weight measurements of vehicles entering and exiting the construction site. This module interfaces with the physical weighbridge infrastructure and automates the process of recording gross and tare weights.

When a vehicle arrives at the weighbridge, the control module initiates the weighing process. The vehicle is directed to position itself on the weighbridge platform, ensuring that all axles are properly placed and the vehicle is stable. Once the vehicle is in position, the control module sends a signal to the weighbridge sensors to capture the gross weight measurement. This measurement represents the total weight of the vehicle, including the load it carries.

After the gross weight is recorded, the vehicle proceeds to the material unloading area. Once the material is unloaded, the vehicle returns to the weighbridge for the tare weight measurement. The tare weight represents the weight of the empty vehicle without any load. The control module captures the tare weight using the same process as the gross weight measurement.

The captured gross and tare weights are then transmitted to the central control unit for further processing and analysis. The control unit calculates the net weight of the delivered material by subtracting the tare weight from the gross weight. This net weight is then compared against the target weight information stored in the material information database to determine if the delivery is within the acceptable range.

The weighbridge control module also incorporates error handling and calibration mechanisms to ensure the accuracy and reliability of the weight measurements. Regular calibration of the weighbridge sensors is performed using certified reference weights to maintain the precision of the system. In case of any discrepancies or sensor malfunctions, the control module generates alerts and notifications for maintenance and troubleshooting purposes.

3.5 Image-based material category verification

Image-based material category verification is an additional layer of validation implemented in the intelligent weighing system to ensure that the delivered materials match the expected categories. This module utilizes computer vision techniques to analyze images of the delivered materials and compare them against reference images stored in the material information database.

When a vehicle enters the construction site and proceeds to the material unloading area, the image-based verification module captures high-resolution images of the delivered materials using strategically placed cameras. These cameras are positioned to provide clear and comprehensive views of the material pile or container.

The captured images are then processed using image recognition algorithms, such as convolutional neural networks (CNNs), which are trained to classify materials based on their visual characteristics. The CNN model is pre-trained on a large dataset of material images, encompassing various categories commonly used in construction projects, such as sand, gravel, cement, steel reinforcement, and more.

The image recognition algorithm extracts relevant features from the captured images and compares them against the reference images stored in the material information database. The database contains a set of verified and labeled images for each expected material category. By comparing the visual similarity between the delivered materials and the reference images, the module can determine the material category with a high level of confidence.

If the image-based verification module confirms that the delivered materials match the expected category, the system proceeds with the standard weighing and documentation process. However, if there is a discrepancy between the delivered materials and the expected category, the module generates an alert and notifies the relevant personnel for further investigation.

The integration of image-based material category verification enhances the overall accuracy and reliability of the intelligent weighing system. It serves as a complementary check to the weight-based verification, ensuring that the right materials are delivered in the correct quantities. This additional layer of validation helps prevent material mix-ups, reduces the risk of construction errors, and improves the overall quality control process on the construction site.

3.6 Integration with gate control and warning systems

The intelligent weighing system is seamlessly integrated with the gate control and warning systems at the construction site to regulate vehicle access and provide real-time alerts for any discrepancies or unauthorized activities.

When a vehicle approaches the entrance gate, the license plate recognition module captures the vehicle's license plate information and verifies it against the authorized vehicle list in the material information database. If the vehicle is authorized, the gate control system automatically grants access, allowing the vehicle to proceed to the weighbridge.

However, if the vehicle is not found in the authorized list or if there are any access restrictions associated with the vehicle, the gate control system denies entry and triggers a warning alert. The alert is sent to the relevant security personnel and site managers, notifying them of the unauthorized access attempt. This real-time notification enables prompt action to be taken, such as directing the vehicle to the appropriate checkpoint for further verification or denying access altogether.

Similarly, when a vehicle completes the weighing process and the delivered materials are verified, the gate control system grants exit permission. If there are any discrepancies detected during the weighing or material verification process, such as a significant weight deviation or a mismatch in the material category, the system generates a warning alert. The alert is sent to the site supervisors and quality control teams, prompting them to investigate the issue and take necessary corrective actions.

The integration of the intelligent weighing system with the gate control and warning systems enhances site security, prevents unauthorized material deliveries, and ensures that any anomalies or non-compliances are promptly addressed. By automating the access control process and providing real-time alerts, the system reduces the reliance on manual interventions and improves the overall efficiency of material management on the construction site.

Furthermore, the data collected by the gate control and warning systems, such as vehicle entry and exit timestamps, access logs, and alert histories, can be analyzed to identify patterns, optimize material delivery schedules, and improve overall site logistics. This data-driven approach enables construction managers to make informed decisions, streamline operations, and enhance the productivity of the construction project.

4. SYSTEM IMPLEMENTATION

4.1 Hardware setup and configuration

The intelligent weighing system's hardware setup consists of various components that work together to enable accurate weight measurement, vehicle identification, and material verification. The primary hardware elements include the weighbridge, license plate recognition cameras, material imaging cameras, and the gate control system [18].

The weighbridge is a critical component of the system, responsible for capturing the gross and tare weights of vehicles. The weighbridge is installed at the entrance and exit points of the construction site, ensuring that all incoming and outgoing vehicles pass through it [19]. The weighbridge is equipped with high-precision load cells that convert the mechanical force exerted by the vehicle's weight into electrical signals [20]. These signals are then processed by the weighbridge control module to determine the accurate weight measurements.

License plate recognition (LPR) cameras are strategically placed at the entry and exit points of the construction site to capture high-resolution images of vehicle license plates [21]. These cameras are positioned at optimal angles and heights to ensure clear and readable license plate images under various lighting conditions. The captured images are then processed by the LPR software to extract the license plate information, which is used for vehicle identification and authorization.

Material imaging cameras are installed at the material unloading area to capture images of the delivered materials. These cameras are positioned to provide comprehensive coverage of the unloading zone, ensuring that all delivered materials are captured in the images. High-resolution cameras with adequate lighting are used to obtain clear and detailed images of the materials, enabling accurate material category verification using image recognition algorithms.

The gate control system is integrated with the intelligent weighing system to regulate vehicle access to the construction site. Automatic barriers or gates are installed at the entry and exit points, and they are controlled by the gate control module. The gate control system receives signals from the vehicle identification and weighing modules to determine whether a vehicle is authorized to enter or exit the site. If a vehicle is authorized, the gates automatically open to allow passage, otherwise, they remain closed, and an alert is triggered.

4.2 Software development for data matching and control logic

The intelligent weighing system's software algorithms and control logic process data from various hardware components and make decisions based on predefined criteria. The software development process starts with integrating data from multiple sources like the weighbridge, LPR cameras, material imaging cameras, and the material information database. This integration ensures all data is correctly formatted, timestamped, and stored in a centralized database.

The vehicle identification module uses advanced image processing and optical character recognition (OCR) to extract license plate information from LPR images, which is then matched against the authorized vehicle list in the material information database.

The weighbridge control module processes electrical signals from load cells to generate accurate weight measurements. It also includes error handling mechanisms to detect and address calibration issues or discrepancies.

The material category verification module utilizes convolutional neural networks (CNNs) trained on labeled material images to classify captured images into predefined categories based on visual similarities with reference images in the material information database.

Gate control system logic integrates with the vehicle identification and weighing modules. It analyzes authorization status and weight data to decide whether a vehicle should be granted access. If the vehicle is authorized and within the acceptable weight range, a signal is sent to open the gate. Otherwise, alerts and notifications are triggered to address unauthorized or erroneous access attempts.

4.3 Database design and interface specifications

The intelligent weighing system relies on a relational database to manage and organize the system's data efficiently while maintaining integrity and consistency. The schema includes tables for vehicle information, authorized vehicle lists, material categories, weight ranges, and transaction records.

Vehicle information tables contain license plate numbers, vehicle types, and associated suppliers or contractors. Authorized vehicle lists store details about vehicles permitted on-site, including their access privileges and restrictions. Material categories are defined in tables with their names, descriptions, and reference images, while target weight ranges consider factors like contracts and project specifications.

Transaction records provide a historical log of each weighing event, including vehicle identification, gross and net weights, timestamps, and material categories, enabling audits, reports, and analysis.

Standardized APIs facilitate seamless data exchange between system modules and the database. These interfaces enable efficient querying, retrieval, and updating. Proper indexing ensures swift data retrieval for frequently accessed tables like authorized vehicle lists and transaction records. Security measures, such as access controls, encryption, and backups, safeguard data integrity and protect against unauthorized access.

4.4 User interface and data visualization

The intelligent weighing system features a user-friendly interface tailored for construction site personnel to monitor the weighing process and access relevant data. Prioritizing simplicity, the main dashboard presents real-time details of vehicles being weighed, including identification, gross and tare weights, and material category. It also summarizes daily transactions, showing total vehicles processed, cumulative material weight, and alerts.

A search and filter function allows users to quickly access specific transaction records by date, vehicle, material category, or weight range. This facilitates efficient historical data retrieval for analysis and reporting.

Data visualization techniques, such as bar graphs and pie charts, are used to highlight material distribution, weight ranges, and supplier performance. These insights help managers identify trends and areas for improvement.

The interface includes a reporting module that generates customizable reports based on criteria like date range, filters, and data fields. These reports can be exported in PDF or Excel for further analysis and sharing.

To ensure data security and integrity, the interface uses role-based access control (RBAC). This limits access based on user roles, ensuring site supervisors, material managers, and administrators only access information pertinent to their responsibilities while preventing unauthorized data modification.

5. CONCLUSION

This research introduces an intelligent weighing system that addresses construction material management challenges through vehicle identification, load verification, and image-based categorization. The system enhances the accuracy and reliability of weighing by automating access control with license plate recognition, preventing unauthorized entry, and using weighbridge modules to capture gross and tare weights, thus minimizing manual errors.

Image-based verification, powered by convolutional neural networks, confirms material categorization, reducing mix-ups and ensuring compliance with project standards. Integration with gate control and warning systems boosts security, issuing real-time alerts for discrepancies or unauthorized activities. Hardware and software components, including weighbridges, cameras, data management, and image recognition algorithms, ensure precise control, data visualization, and decision-making insights.

Adopting advanced technology in material management increases efficiency, transparency, and accountability, reducing labor costs and errors while providing data for improved decision-making and project planning. However, successful implementation requires careful assessment of infrastructure and budget, personnel training, and integration with other enterprise systems like inventory and accounting.

Overall, this system offers accurate, secure, and efficient tracking of construction materials, promising increased productivity and profitability. Future research should emphasize improving scalability, interoperability, and user experience to encourage widespread adoption.

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