

Automated Transportation Asset Inventory System Using Self-Drive, Drones, and AI for Optimized Pavement Maintenance Management

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Abstract - This study presents a comprehensive model for automating transportation asset inventory and pavement marking maintenance using a synergistic approach that incorporates GPS-enabled self-driving vehicles, drones with pre-programmed routes, Artificial Intelligence (AI), and the European GRASP optimization algorithm. By integrating advanced imaging techniques, such as LiDAR and high-resolution cameras, with AI-driven data processing, the system enables high-frequency, high-precision asset detection, condition classification, and optimized maintenance scheduling. The proposed framework addresses the inefficiencies of current manual and semi-automated practices, introducing predictive analytics for proactive maintenance planning. Integration with Geographic Information Systems (GIS), machine learning, and control chart methods, including Shewhart algorithms, allows for real-time monitoring and decision support. The study highlights significant potential benefits, including reduced inspection costs and time, enhanced road safety, and improved compliance with visibility and reflectivity standards. While implementation challenges such as high initial costs and institutional adaptation exist, the modular, scalable design offers substantial operational and safety advantages for state and national transportation agencies.

Keywords - Artificial Intelligence, Highway Safety, Maintenance Operations, Self-Driven Vehicles and Drones, LiDAR Technology.

1. Introduction

The automation of transportation asset inventory through the integration of artificial intelligence, advanced imaging, and machine learning is set to revolutionize how we manage and maintain critical road infrastructure. Traditional methods, which are often labor-intensive, time-consuming, and prone to inaccuracies, frequently result in increased costs and delayed maintenance. By combining self-driven tools with advanced imaging techniques, such as LiDAR and high-resolution cameras, transportation agencies can acquire

comprehensive data mapping, refine traffic predictions, and enhance route planning and management. Once these data are obtained and using GPS Geo-positioning Information Systems (GIS), it is proposed to create a new user-friendly interface powered by Artificial Intelligence (AI) enhanced with European models, which will serve to provide decision-makers with timely information to make improved decisions for routine maintenance and long-term rehabilitation of the state roads. This combination not only reduces reliance on subjective manual processes but also significantly increases the repeatability and cost efficiency of the entire asset inventory lifecycle. The implementation of AI-driven systems, combined with mobile and cloud computing, provides a cost-effective solution that can be utilized nationwide by the Department of Transportation (DOT), particularly for those with limited budgets.

This work will focus on maintaining the most critical safety and guidance assets on any roadway system, specifically pavement markings. Faded or missing striping compromises safety, increasing the risk of accidents and reducing the effectiveness of the road network. Regular assessment and timely re-striping are essential to maintaining a safe and efficient transportation system. However, it is not limited to pavement markings as it can be integrated with many other vital assets in comprehensive maintenance. The application of AI has the potential to address critical challenges in the transportation industry, including pollution reduction, improved safety, and traffic congestion alleviation [1].

2. Literature Review

Modern transportation infrastructure management requires efficient and accurate methods for assessing and maintaining roadway assets, particularly pavement markings, which are essential for safety and traffic control [2].

The author discusses the potential of mobile LiDAR technology for collecting 3D point cloud data in urban environments. He mentions how the system has been adapted

to recognize critical street features that are part of transportation assets. This literature reports on advances in mobile LiDAR technology and its applications in road information inventory. Our review highlights the significant potential of mobile LiDAR technology for asset inventory detection and subsequent processing.

Conventional approaches to pavement marking inventory and management frequently rely on manual inspection and data collection techniques, which present inherent limitations [3].

The author raised that Roadway asset inventory data is essential in making data-driven asset management decisions. Despite significant advances in automated data processing, the current state of the practice is semi-automated. The proposal is a platform that provides an offline system onboard the survey vehicle, which runs a lightweight and speedy data network on each collected roadway image and identifies traffic signs in real time. The success metrics based on this demonstration indicate that the algorithm was effective in identifying traffic signs with high accuracy.

3. Current Pavement Marking Management Systems

Many states face severe budget constraints for both large-scale and routine maintenance. Other agencies experience operational inefficiencies, resulting in state roads with severely deteriorating assets, including striping, which directly impacts motorist safety. Currently, pavement marking practices are often managed using systems that are not synchronized with other maintenance and construction scheduling systems, leading to inefficiencies and potential conflicts. This results in excessive costs or double work, wasting time and resources on the one hand, and on the other, directly impacts motorist safety, increasing the risk of accidents and compromising the effectiveness of traffic control measures.

Deteriorated or missing pavement markings, such as lane dividers and stop lines, undermine drivers' ability to interpret road geometry and follow traffic regulations, thereby increasing confusion and the likelihood of human error.

Furthermore, compromised signage and faded striping weaken the integrity of traffic control systems, leading to reduced compliance with driving directions, yield instructions, and right-of-way rules. In high-traffic or high-speed areas, these failures can have especially severe consequences, resulting in crashes, traffic slowdowns, and, in the worst cases, fatalities. Vulnerable road users—such as motorcyclists, cyclists, and pedestrians—are at even greater risk due to their limited protection and dependence on clear road guidance for safe navigation.

Traditional methods, which are often labor-intensive, time-consuming, and prone to inaccuracies, frequently result in increased costs and delayed maintenance. By combining AI-driven tools with advanced imaging techniques such as LiDAR and high-resolution cameras, transportation agencies can acquire comprehensive data, refine traffic predictions, and enhance route planning. This focus not only reduces the reliance on subjective manual processes but also significantly increases the repeatability (consistency and reliability of inspection or measurement results) and cost-efficiency of the entire asset inventory lifecycle.

4. GPS Self-Driven Vehicle and Drone Technology in Asset Inventory

The integration with self-driven vehicles equipped with new GPS mapping technology and pre-programmed drones represents a significant advancement in automated transportation asset inventory. Although this type of technology isn't new, it will be the first time it has been used for this purpose. Only a few states have begun pilot testing, installing cameras on the vehicles of field personnel. It's a good initiative, but far from being efficient.

One way this technology has been tested is in self-driving taxis. These cars can create a 3D model mapping scan of their surroundings in real-time, demonstrating the enormous capacity of these systems. In the same way, Drones with pre-programmed routes would also take off at low altitudes, just as they would for advertising events; the difference would be the equipment and sensors they carry. The difference lies in the equipment that can be equipped, depending on which asset is to be prioritized.

Self-driven vehicles equipped with high-precision GPS and advanced sensors can systematically traverse roadways, capturing detailed data on pavement conditions, sign visibility, and the state of other infrastructure elements [4].

These drones can be outfitted with high-resolution cameras and LiDAR sensors that can detect and mapping retroreflective elements embedded in or attached to road assets such as traffic signs, lane markings, delineators, guardrails, and mileposts. The fusion of data from GPS and georeferencing information systems (GIS) enables the precise identification of assets, allowing for accurate location mapping and temporal monitoring of infrastructure degradation.

Retroreflective materials are designed to return light toward their source, making them highly visible in low-light conditions and ideal for automated detection, whether using active or inactive illumination techniques. These systems can precisely locate and identify assets based on their

retroreflective signatures, for example. The collected data can then be processed into a GIS-based database to generate detailed inventories, assess asset conditions, and prioritize maintenance and replacement activities.

It is essential to emphasize that the goal is not to eliminate any personnel, but rather to provide them with a powerful tool that will save them time and reduce the associated operational costs. Additionally, this staff will need to validate the data generated by the sensors in a representative sample, especially during the early stages of the pilot tests, to implement the system.

5. AI Integration in Transportation Infrastructure

Artificial intelligence has the potential to transform various industries, including transportation, by enabling intelligent systems to analyze and improve transportation networks through the collection of data from sensing devices. AI algorithms can process vast amounts of data collected from various sources, including GPS-enabled vehicles, drones, and roadside sensors, to extract meaningful insights and powerful patterns. This can lead to more efficient and cost-effective asset inventory management systems, improved safety, and reduced traffic interventions.

The fusion of AI with advanced imaging and record systems can significantly enhance pavement marking management [5].

6. Data Processing and Reflectivity Measurement

This data can be used to ensure that pavement markings meet the minimum retro-reflectivity standards for both daytime and nighttime visibility, as specified in the Manual on Uniform Traffic Control Devices (MUTCD), which is used by transportation agencies and often referenced by the private sector. AI can use the collected data to mapping all road assets, assess them, classify them by characteristics, and present them in a user-friendly, easy-to-interpret graphical interface. It can suggest an optimal, cost-effective routine maintenance sequence, for example. Once the critical intervention point is reached, it can also evaluate other traditional parameters, such as traffic volume and accident data, to suggest construction or major maintenance projects.

6.1. Features of integration with artificial intelligence:

6.1.1. Machine Learning Models. Programs or algorithms can learn patterns from data to make predictions, classifications, or decisions without being explicitly programmed for every possible scenario. This enables them to classify asset conditions and detect anomalies (e.g.,

missing reflectors, faded paving markings).

6.1.2. Image Recognition Algorithms. Analyze visual input (photos or video frames) to understand and label the contents of the image, similar to how humans look at a picture and recognize roads, signs, vehicles, or pavement damage. This is achieved by training on labeled datasets to identify asset types and degradation patterns.

6.1.3. GIS Integration. GIS (Geographic Information System) is a database system that captures, stores, analyzes, and displays data tied to specific locations on Earth. The model can be linked to geographic data, enabling it to analyze and visualize information in a spatial context on a map for historical comparison.

AI-based recognition algorithms accurately identify and classify:

- Pavement markings (centerlines, stop bars, crosswalks)
- Regulatory and warning signs (shape, size, orientation)
- Reflectivity levels (for MUTCD compliance)
- Obstructions or visibility issues (e.g., overgrown vegetation)
- Object markers (Delineators, raised object marker (RPMs))

7. GRASP European Model

GRASP model is a known optimization metaheuristic used in engineering and operations research, and it's being adapted or considered in European road maintenance systems. Greedy Randomized Adaptive Search Procedure (GRASP) is a powerful optimization tool that helps agencies prioritize and schedule road maintenance activities efficiently, especially when integrated with AI and geospatial data, using combined optimization in which each iteration consists of two main phases:

Construction: A feasible solution is constructed greedily but randomly.

Local condition search: This solution is improved with a local search to reach a local optimum.

This process is repeated many times, and the best solution found in all iterations is taken as the result. Accepts solutions worse than the current one with a certain probability, but within an acceptable threshold. This "worse" outcome is allowed, in the hope of moving away from the local optimum and further exploring the solution range. Accepts a solution if its worsening does not exceed a certain fixed or decreasing threshold.

Commonly used models, integrated with the GRASP European model, offer an improved, structured framework for optimizing routine and responsive pavement maintenance operations. This model provides a comprehensive approach to pavement management, incorporating data collection,

analysis, and decision-making processes to ensure the efficient allocation of resources and the development of effective maintenance strategies.

The data generated through self-driven vehicle surveys and drone-based inspections can be fed into this integrated model to assess pavement conditions, predict deterioration rates, and prioritize maintenance needs. Incorporating the GRASP model into the AI algorithms can further refine the decision-making process by identifying optimal maintenance schedules and resource allocation strategies, including routine maintenance.

It's an approach that most transportation agencies currently lack, but it's a global trend we can't ignore. Meanwhile, systems like COMPAS, which is highly accepted and used by the Florida Department of Transportation, for example, take a much more straightforward and technical approach. It works, but it's not efficient. That's why integrating it, not replacing it, with the European system would be much more effective and efficient. It is already being used in Spain, with the collaboration of the University of Chile.

Optimal pavement maintenance programs based on a hybrid GRASP-Threshold Accepting [6].

In this research, the model integrating GRASP principles was applied to real road network data in the Valencia region (Spain), with the participation of institutions in Chile, and was complemented with simulated scenarios. These are some of the results:

- The enhanced GRASP program achieved 40% greater long-term effectiveness (LTE) compared to the traditional reactive approach.
- Sensitivity analysis revealed that higher investment in the early years significantly enhanced overall effectiveness.

8. Construction and Maintenance Scheduling Systems

Synchronizing the proposed model with construction and maintenance scheduling systems is essential for ensuring seamless coordination between asset management, infrastructure projects, and maintenance operations. By establishing a bidirectional data flow between the asset inventory system and scheduling platforms, agencies can move toward a more proactive and responsive maintenance paradigm.

Scheduling synchronizing sounds is simple, but it isn't, due to the enormous variability of situations that occur in the field simultaneously, as well as the different agencies that must work together under time and budget constraints to achieve optimal state highway maintenance, which means ensuring the functionality of all components.

The integration will enable automated updates to construction schedules based on real-time data collected from the field, such as recent open permits or emergency utility repairs. Thus, delays will be reduced, and disruptions to traffic flow will be minimized.

This synchronization not only optimizes resource allocation but also enhances communication and collaboration among different departments and stakeholders involved in infrastructure management.

9. AI Model Development

AI algorithms, including machine learning models, will be developed to analyze the data collected. This model will be capable of quickly and reliably identifying and classifying pavement markings, signs, and other transportation assets.

The algorithms will be trained on a large dataset of images and sensor data to ensure accuracy and robustness. They will focus on identifying the location and condition of pavement markings and displaying data on a geolocation database to suggest an optimal maintenance schedule.

Integration algorithms will utilize advanced statistical process control techniques, including control charts and Shewhart algorithms, to identify potential defects or anomalies in pavement markings. It will establish acceptable tolerance ranges for key performance indicators, including retro-reflectivity, color, and line width, based on the Manual on Uniform Traffic Control Devices (MUTCD). Besides, it will incorporate predictive modeling techniques, such as regression analysis and time series forecasting, to anticipate future maintenance needs and proactively schedule repairs before pavement markings deteriorate to unacceptable levels or reach a critical failure point.

The key to this proposed developed asset inventory and pavement marking management system will be its seamless integration with European models and existing construction and maintenance scheduling systems used by DOT agencies nationwide. This will involve establishing data exchange protocols and APIs to enable real-time information sharing between the asset management system and scheduling platforms, allowing for suggested updates to ongoing construction schedules and adjusting the routine maintenance schedule. For example, in areas close to where construction begins or during emergencies, routine maintenance work can be paused, while it can be suggested in another critical area.

All integrated systems will trigger automated alerts and notifications based on real-time data collected from the field, providing decision-makers with timely information.

Through API integration, real-time data collected from field operations can automatically trigger updates to construction schedules, optimizing resource allocation and minimizing traffic flow disruptions by proactively scheduling maintenance activities [7].

10. Results Expected

Results may vary depending on the implementation and structure of each state transportation department agency or private industry, as well as specific field conditions; however, the goal is to establish the proposed system as a standard for creating a common language that everyone can understand.

10.1. Improved Pavement Marking Condition and Compliance. Increased compliance rate across all road classes based on MUTCD guidance, including the state road highway system. Enhanced Safety and Reduced Liability Risks, proactive maintenance of pavement markings will improve visibility and guidance for drivers, reducing the risk of accidents and minimizing liability exposure for transportation agencies [8].

10.2. Faster and More Accurate Asset Inventories. Autonomous ground vehicles, drones, and AI-enabled analytics transform the traditionally manual and periodic process of asset inventory into a continuous, high-frequency, and high-precision system. This shift enables DOTs to maintain an up-to-date digital record of roadway assets, essential for effective planning, compliance, and safety

10.3. Optimized Maintenance Planning and Execution. The development of a customer-oriented maintenance decision support system can help with benchmarking work units' performance and evaluating the efficiency of meeting customer needs. By integrating AI-driven analytics, real-time data fusion, and predictive modeling, the system enables more effective decision-making for traffic professionals [9].

10.4. Increased Operational Efficiency. Crews receive precise, GPS-based work orders, reducing planning overhead and idle time. Despite the high initial cost, regular inventory operations result in fewer trips, which means less expense and increased efficiency. Providing staff with the right tools enables them to make more efficient decisions. Agencies can optimize maintenance resource allocation by prioritizing sections that need immediate repair.

10.5. Safety Benefits. Early detection of unsafe road conditions, such as missing striping lines, faded stop bars, or obstructed signage, can significantly reduce the risk of accidents, especially in extreme weather conditions or at night. In addition, fewer crew hours spent on the roadway reduce exposure and associated accident risk.

10.6. Data-Driven Decision Making. By integrating real field conditions data collection and an AI-powered analysis model, transportation agencies can make better decisions that optimize resource allocation, improve safety, and minimize disruptions. These systems can predict pavement and striping failures based on traffic and other conditions, enabling preemptive maintenance and promoting sustainability.

11. Proven Benefit

Such advancements not only streamline operations but also offer a cost-effective solution, particularly for agencies with budget constraints, by minimizing the need for extensive manual data collection, facilitating optimal information management, and enabling integration with other systems.

- Approximately 60–90% reduction in inspection time and costs. Advancing Condition-Based Maintenance: Drone and Data-Driven Solutions for Utilities [10].
- More than a 15% increase in the cost-efficiency of maintenance planning. Multi-objective optimization in highway pavement maintenance and rehabilitation project selection and scheduling: A state-of-the-art review [11].
- Crash reductions due to better-maintained markings and signs.
- Exact, up-to-date visibility into asset conditions for engineers, planners, and stakeholders.

12. Accuracy of Asset Inventory and Data Acquisition

To ensure data accuracy and reliability, a quality control process must be implemented, including automated AI validation checks and manual reviews of asset data. A framework for continuous validation and improvement based on feedback from field personnel and stakeholders must also be implemented.

The proposed system, with the help of field personnel and the validation set, can keep the inventory much more up to date than the current system. This is what we refer to as an accurate resource inventory. Based on this, we can say that the decision-maker will have a very precise tool to make better and more efficient decisions. The proposed system is not intended to replace human decision-making, but rather to provide the necessary elements to enhance it.

There are currently mapping systems on the market that are impressive in their power and capabilities. Whether using this technology on foot, in a self-driving car, or assisted by drones with pre-programmed routes, these cameras can take us to a whole new level in terms of accuracy and mapping of road features. That's why we can program it and teach it to recognize the characteristics that are useful for each

particular case, whether in public or private industry.

The integration of IoT technology in road maintenance will aid in the design and maintenance of pavement, including the collection of data from sensors that measure environmental conditions and structural vibrations. IoT-enhanced smart road infrastructure systems for comprehensive real-time monitoring [12].

13. Limitations

Although the proposed system offers significant advancements in transportation asset management, several inherent limitations must be acknowledged and addressed to ensure its successful implementation and widespread adoption. Consequently, the transition to this advanced system might entail significant initial investments in specialized equipment, software licenses, and comprehensive training programs for personnel, potentially posing a financial challenge for some agencies with limited budgets. However, the long-term benefits far outweigh the initial cost associated with it. Some other limitations are as follows:

13.1. Greater computational data and technical complexity in implementation. Safeguarding sensitive information from unauthorized access and cyber threats is critical. Robust security measures, including encryption and access controls, should be implemented to protect the integrity and confidentiality of asset data. An advanced technologies ensemble, interoperability with existing systems, and multidisciplinary coordination are required.

13.2. Requires more integrated and up-to-date data (accidents, friction, drainage, etc.). While the system's modular design promotes scalability, adapting it to diverse DOT requirements and legacy systems can be a complex process. Operability issues may arise when integrating the system with existing infrastructure and software platforms, creating an intuitive dashboard for users (engineers, planners) to visualize condition ratings, alerts, and maintenance recommendations.

13.3. Requires staff training and institutional validation. Thorough testing and validation are necessary to ensure seamless integration and optimal performance across different environments. Again, the intent is not to eliminate

maintenance personnel, but rather to provide them with a powerful tool; this staff will have to validate data generated by the sensors in a representative sample.

13.4. There may be resistance to changing from a proven system, such as the Computerized Maintenance Management System for Pavement, like the COMPAS method in Florida. Demonstrating the benefits of the system in terms of improved safety, efficiency, and sustainability can help alleviate skepticism and promote widespread adoption.

14. Conclusion

This research presents a comprehensive approach to automating transportation asset inventory and optimizing pavement marking management through the integration of GPS self-driven vehicles, drones, AI, and the GRASP European model. The integration of these technologies and methodologies will contribute to streamlined asset management processes, minimize operational inefficiencies, enhance sustainability through optimized resource utilization, and improve safety outcomes through proactive maintenance and the timely identification of potential hazards.

Automated transportation asset inventory system represents a paradigm shift in pavement marking management, combining cutting-edge technology with proven European standards. By integrating autonomous vehicles, drones, AI, and the GRASP model, transportation agencies can achieve unprecedented efficiency, safety, and compliance in their maintenance operations while significantly reducing costs and improving service quality. Partnerships with companies like Google Maps or Apple Maps can help develop extensions for these applications, which may include reporting options for ordinary users to flag unpaired pavement and striping conditions.

The system's modular design ensures scalability and adaptability to various DOT requirements, while its integration capabilities guarantee seamless operation within existing workflows. The expected return on investment, combined with improved safety and compliance outcomes, makes this system an essential upgrade for modern transportation infrastructure management.

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