Autonomous Track Inspection Systems – Today and Tomorrow

Gary A. Carr
Federal Railroad Administration,
Office of Research & Development
1200 New Jersey Avenue SE
West Building, 3rd Floor
Washington, DC 20590
gary.carr@dot.gov

Ali Tajaddini, PE
Federal Railroad Administration,
Office of Research & Development
1200 New Jersey Avenue SE
West Building, 3rd Floor
Washington, DC 20590
ali.tajaddini@dot,gov

Boris Nejikovsky
ENSCO, Inc.
5400 Port Royal Road
Springfield, VA 22151
nejikovsky.boris@ensco.com

Word Count: 4,338

ABSTRACT

Since 1970, automated track inspection systems have gone from limited use as a quality assurance tool by a few railroads to a key element to track asset management and safety assurance. Today, some form of automated inspection for track geometry, rail profile and/or gage restraint measurement regularly is used on most Class I US railroads. The data from these systems plays a key role in both safety assurance and maintenance planning. Over the last decade, a new generation of autonomous automated track inspection systems has emerged. These include Vehicle/Track Interaction (V/TI) Measurement systems and more recently Autonomous Track Geometry Measurement Systems (ATGMS). There are three critical phases in the introduction of any new technology into the railroad track inspection arena - technology development, recommended practices for acquisition and use of the data, and regulatory reform to allow for and promote the benefits of the technology insertion. This paper briefly reviews the history of autonomous track inspection systems, describes the current state of the art, and provides an initial "roadmap" for the railroad community to use in developing and implementing plans and programs to take full advantage of this emerging technology for the benefit of safety and performance.

INTRODUCTION

The number of track caused derailments in the United States has been gradually decreasing since the 1970s, but the rate of the decrease is slowing down. New methods of derailment prevention, including new track inspection methods, are needed to drive the number of derailments down further. In addition to safety considerations, the new track inspection methods can have operational benefits. They can help to reduce in-service track failures, therefore helping to maximize the capacity of the freight and passenger railroads.

Current methods for track inspection include either visual inspection by track inspectors or automated inspection from dedicated inspection cars. In this context, automated inspections are those in which key measurements are collected by instrumentation that is attended to by one or more operators. An inspection car can be self propelled, towed or can be a hi-rail vehicle, but in all cases it is a dedicated car carrying specialized equipment to measure the track with trained operators to run the equipment and conduct the inspection. Since the 1970s, the use of automated track inspection systems has grown to become a key element to track asset management and safety assurance. Today, some form of automated inspection for track geometry, rail profile and/or gage restraint measurement is regularly used on all Class I US railroads. Automated inspection has provided an objective method for the evaluation of track conditions that has contributed to the decrease in the derailments rates. However, methods involving automated inspections typically require track time, expensive systems and dedicated manpower. New emerging technologies can significantly improve current methods.

Autonomous track inspection is a process of inspecting the track from revenue trains using unattended instrumentation with minimal direct involvement. New autonomous track inspection technologies have been developed utilizing revenue service trains equipped with data collection equipment that employs wireless communications to provide inspection data with dramatically increased frequency and reduced cost. This type of technology will have significant ramifications on the nature of track inspections, maintenance practices, and government regulations. By making inspection systems autonomous, the data can be collected more frequently without consuming track time. The use of autonomous inspection technologies will result in earlier detection of track defects and changes in maintenance practices from reactive to preventative, ultimately reducing the number of track caused derailments throughout the railroad industry.

This paper will provide a brief background on autonomous track inspection systems and technologies, describe their uses to date, and discuss multiple issues and ramifications associated with their implementation. An initial “roadmap” for the railroad community to use in developing and implementing plans and programs that take advantage of this emerging technology will also be provided.

BACKGROUND

Implementation of Autonomous Track Inspection Technology to Date

The first systematic use of autonomous track evaluation in the United States took place on the Acela trainsets, the high-speed trainsets operated by the National Passenger Railroad Administration (Amtrak) on the Northeast Corridor (NEC). Amtrak’s implementation of autonomous technology was in response to Federal Railroad Administration (FRA) regulations.

In 1998, the FRA introduced Subpart G of the Track Safety Standards that addressed passenger train operation at speeds above 90 MPH in Track Classes 6 through 9 [1]. 49 Code of Federal Regulations (CFR) 213.333 required daily monitoring of car body and truck frame accelerations onboard equipment operating at speeds in excess of 125 MPH. To satisfy this requirement, Amtrak equipped its Acela high-speed train sets with Autonomous Ride Monitoring Systems (ARMS) in 2000; the concept of the ARMS is illustrated in Figure 1. The ARMS units are based on technology developed by the FRA Office of Research and Development and ENSCO, Inc. The systems allow remote, autonomous monitoring of performance of the Acela train sets from a vehicle/track interaction perspective through the measurement of car body and truck accelerations. The acceleration data is used to evaluate rough riding locations and/or poor performing train sets and report incidents to a response team for corrective actions. A typical installation of the Amtrak ARMS system is pictured in Figure 2. Amtrak's systems have been in operation for nine years, and the data provided by these systems is used daily by Amtrak maintenance forces and management personnel to ensure the safety and quality of Amtrak's high-speed service. In 2002, Maryland Transit Administration's MARC commuter service followed Amtrak's lead and equipped a number of their trains with similar systems.

In 2004, the Union Pacific Railroad became the first freight railroad in the United States to adopt technology of this nature. Application of the technology employed by Amtrak and MARC was augmented by the use of axle-mounted accelerometers to identify battered joints, misaligned switches, damaged frogs and other high-impact events. Currently 200 autonomous systems targeting vehicle/track interactions are used across the Class I US railroads with the data from the systems being fed into railroad maintenance planning processed on daily basis.

The experience of Amtrak and the other Class I US railroads illustrated the effectiveness of autonomously monitoring potentially dangerous track conditions causing undesirable vehicle responses. Several parties have taken steps to build upon this success by developing autonomous track geometry measurement systems. In 2004, ImageMap developed its Unattended Track Geometry Measurement System (UTGMS) and installed it on several revenue trains in the United Kingdom. In 2008, the FRA installed the Autonomous Track Geometry Measurement System (ATGMS), developed on behalf of the FRA by ENSCO, on Amtrak's Auto Train operating between Virginia and Florida. The ATGMS detects, locates, and reports potential track defects in near real-time to a web-based inspection data management system for review and remedial action. The principle behind the FRA's ATGMS is shown in Figure 3.

While use of autonomous technology to evaluate track conditions is broadly accepted in the United States, the use of autonomous technology to directly measure track geometry as part of regular maintenance and safety assurance practices is still in its infancy. Although the ATGMS and UTGMS handle data collection and processing differently, they both fulfill the objective of the technology – inspecting the track from revenue trains using unattended equipment without operators. Although the confirmation of defects on the ground and remedial actions still require human intervention, autonomous track inspection provides a significant step forward by increasing the frequency and decreasing the cost of track inspection.

Core Technology in Autonomous Track Inspection Systems

As illustrated in Figures 1 and 3, the autonomous track inspection technology established to date generally includes three major components: onboard units, wireless communication links, and processing servers.

- *Onboard Units* – The portion of the system located on the vehicle generally consists of a series of sensors, a computing platform, and location determination technology.

  A dramatic increase in computer power and reliability, combined with a decrease in processor size, is one of the enabling factors for autonomous monitoring. Onboard equipment is becoming small enough, reliable enough, and sophisticated enough to conduct most of the operations currently performed by inspection car operators. These operations include instrumentation verification, generation of data, location marking, and exception evaluation. Although there are still operations where it is difficult to replace a human operator, particularly when something malfunctions or unexpected situations arise, these situations can be identified and the data handled appropriately in an automated fashion.

  Global Positioning System (GPS) technologies are critical to autonomous inspection in that they provide location of the detected defects in absence of an operator. Onboard GPS based location systems can have different levels of accuracy and sophistication from regular GPS receivers to Differential GPS (DGPS) to high end DGPS assisted inertial navigation systems. The use of standard GPS provides the cheapest solution, but the associated accuracy is about 40 feet (in 95% of the cases) under normal conditions with a clear view of the sky. The accuracy of GPS is significantly affected by various atmospheric conditions, as well as local terrain and can be interrupted by dense foliage, overpass bridges, tall buildings and other obstructions. At the other end of the spectrum is DGPS assisted inertial navigation systems. These systems provide uninterrupted and more accurate GPS locations even when GPS signal is temporarily interrupted or obstructed. The accuracy of these systems, depending on the type of the DGPS and inertial sensors utilized, can be as high as 1 foot. This increased accuracy comes at a cost in that it is achieved by using more expensive hardware and paying for differential correction services.

- *Processing Servers* – A key element on an autonomous inspection system is a central server to which data is transferred. This facility features data processing capabilities, a database management system, and Geographic Information Systems (GIS) applications to facilitate reporting of areas of interest.

  The nature of autonomous inspection systems greatly improves the productivity of inspection operations but can increase the volume of data to be considered. An efficient data management and reporting system is necessary to create uniform data storage, and increase the efficiency of reporting issues. GPS coordinates or other location data associated with defects are not sufficient unless there are underlying maps that show information associated with track and other rail infrastructure. This allows for conversion of location data reported by the onboard autonomous systems into standard linear railroad referencing (subdivision, MP, FT, track number). Currently, most railroads in the United States have some kind of GIS database with locations of rail infrastructure. The accuracies of these databases have a direct effect on the reliability of the location of the autonomously reported exceptions. At this time, the accuracies of GIS databases of most US carriers are not sufficient to reliably differentiate the track number using GPS data alone. However, with the advent of Positive Train Control (PTC) in the United States this is expected to change. The accuracies of GIS databases are expected to increase to a level where track number will be correctly determined.

- *Communication Links* – The manner in which data is transferred between the onboard units, the central processing servers, and the data recipients is an important feature of any autonomous inspection system. It affects the way in which measured data is uploaded to the central processing servers, and processed information is distributed to inspectors or maintenance personnel.

Wireless communication is another critical enabling technology used for retrieval of data from the onboard systems and providing remote monitoring and maintenances to the systems. Different communications approaches have been used. The aforementioned systems employed by the Class I US railroads, as well as the FRA ATGMS, uses publicly available commercial 2g and 3g data networks, while ImageMap has employed dedicated 802.11 readers installed at the end stations of the surveyed routes. In any case, the bandwidth of available wireless communications continues to increase providing opportunities to collect and upload larger data sets.

Data collected by autonomous track inspection systems can be made available to stakeholders through a variety of ways including electronic email reports, dedicated websites, and transfer to railroad data management systems.

PHASES OF AUTONOMOUS TRACK INSPECTION TECHNOLOGY INTRODUCTIONS

Similar to other revolutionary technologies, the introduction of autonomous inspection technology presents challenges that must be addressed by operators as well as regulators. These challenges include the development of safe and reliable technology, the establishment of procedures and recommended practices for system and data use, and the development of appropriate regulations. Issues associated with each of these challenges will be summarized and addressed in the following sections. Where appropriate, lessons learned at the onset of autonomous inspection will be related.

Development of Safe and Reliable Technology

From the hardware's point-of-view, autonomous inspection devices face similar challenges and requirements to other equipment installed on railroad vehicles requiring high levels of reliability including:

- Sufficient power to allow the system to function under all required conditions;
- Protection from operating environment and tampering;
- Redundant safety protection for both vehicle and personnel;
- Fire/smoke resistance requirements;
- Technical support for operation and repairs.

The onus for system safety and reliability falls on the supplier working in close coordination with the railroad. Depending on the type of the vehicle, the autonomous systems must comply with various regulations. For example, equipment installed in locomotive cabins or passenger cars must comply with a number of strict federal regulations including fire and smoke requirements. Equipment installed on the bogie or under the trains should have redundant safety mechanisms to protect them from falling on the track and causing derailment and must comply with clearance requirements; in some cases, this equipment must be subject to strict electro-magnetic interference (EMI) restrictions. In addition, equipment installed on the bogie cannot negatively affect dynamic bogie performance which may necessitate weight and size limitations. It should also be noted that some inspection systems employ lasers or high voltage. These devices must be adequately shielded in compliance with regulations so that they do not affect safety of railroad workers, passengers or people near the track.

Based on lessons learned by railroads that have implemented this type of technology, the following efforts should be considered prior to the deployment of autonomous inspection systems:

- *Maintenance Procedures*: Clear documentation of the system and its installation should be provided to, and accepted by, the appropriate maintenance departments in order for railroad personnel to develop standard procedures to address operation and maintenance of the vehicles upon which the inspection system is installed. This will provide shop personnel with instructions on how to handle maintenance work on the vehicle that may be impacted by the inspection system's presence on the vehicle. It should also have warnings to minimize the chances of damage or disconnection of the inspection system during routine maintenance activities. Maintenance procedures should also be established for the autonomous system itself to clearly establish the roles of railroad personnel and suppliers in performing maintenance and calibration activities. Maintenance procedures must include safety precautions in the event that lasers or high voltages are associated with the inspection system.

- *Operational Procedures*: Documentation and emergency instructions should be posted or accessible in all rail vehicles on which the autonomous inspection systems are installed to give the onboard crew and maintenance personnel directions in the event of issues with the system, especially in the event that the issues causes the inspection system to interfere with the mechanical or electrical operation of systems on the vehicle or the vehicle itself.

Due to the nature of its deployment, autonomous inspection technology has the additional requirement of the following features:

- Low false-alarm and missed detection rates;
- Remote diagnostic capabilities;
- Remote software updates and enhancements;
- Remote or self-recovery in the event of power interruptions;
- Reliable communications coverage and bandwidth.

The responsibility for system reliability with respect to these issues falls on the suppliers to ensure that widespread use of autonomous inspection technology is not adversely affected by reliability issues, especially those affecting confidence in data such as missed detections and/or high false alarm rates. This can be difficult when components operate in the severe and challenging railroad environment. Optical sensors pose particular challenges; with autonomous systems, regular manual cleaning of lenses and windows are not realistic. Autonomous systems employing optical sensors must be adequately protected to minimize the need for regular cleaning or have automated cleaning mechanisms. Accessibility of autonomous inspection systems can be severely limited due to revenue service operations; railroads may not delay movements or park vehicles to repair a track inspection system. To that end, systems of this nature must have means of self recovery or automated/remote recovery to be able to overcome non-critical glitches or component failures. In addition, these systems must have some level of redundancy for critical functions, high mean time between failures (MTBF), high level of maintainability and serviceability so that if the system fails, maintenance personnel can repair the system with short time frame that may be available.

Based on past experience, pilot applications of autonomous inspection technology on limited routes often serve as an opportunity to identify issues, and validate the approach and results of the system while minimizing railroad investments in time and effort required.

Establishment of Procedures and Recommended Practices for System and Data Usage

The use of autonomous inspection technology offers many benefits to the railroad industry, including high inspection frequencies, allowing for additional data availability for improved forecasting and trend analysis, and near instantaneous availability of data. This increase in data brings several challenges for the railroad, including:

- Vast amounts of information that must be considered as data will be collected at a much higher frequency as compared to traditional methods;
- The manner in which information collected with autonomous systems will be integrated and compared with data collected with the traditional, on-going inspection practices;

- Validation of events identified by the autonomous inspection system given the increased frequency in which data is reported, especially at the onset of the autonomous inspection program.

Prior to the full implementation of autonomous inspection technology, the railroad should have a clear plan on data usage. As is often done in automated inspection programs, different thresholds are used to identify issues that could grow into defects. With increased reporting frequencies, new thresholds may be warranted to monitor defect growth rates with increased sampling rates and projections of when the defects will become critical. Railroads will need to develop practices to appropriately address these changing conditions.

Follow-up activities based on reports generated by autonomous inspections represent a particular challenge to the railroad industry. The potential exists for extra costs without immediate significant benefit, especially during the introduction of the technology during the critical stage of validation, “qualification,” and process modification. Based on experiences with the previously cited implementations of autonomous inspection systems, pilot applications can afford an opportunity for operators to gradually develop response plans, formulate appropriate thresholds where applicable, and grow accustomed to data flow rates.

Confidence in the data reported with this technology can often be bolstered by considering the existence of “repeated events” on consecutive surveys as a validation mechanism. Although this represents a logical approach during the initial stages of autonomous inspection deployment, this is accompanied by risk – the “knowledge” of a potential defect without immediate remedial action. This is an extremely critical issue in that it not only represents increased liability for the railroad but a regulatory issue as well. This leads directly into the third category of challenges – the development of appropriate regulations.

Development of Appropriate Regulations

Current regulations, which are largely predicated on visual inspections and infrequent but technically detailed automated inspections, may not be appropriate for the manner in which defects will be identified with autonomous track inspection systems. A railroad track inspector is obligated to correct (initiate a repair of) or protect (slow order) the track before the next train once a defect to the FRA Track Safety Standards has been determined to exist during an on-the-ground inspection. The FRA Office of Safety has generally taken the position that track defects detected during an automated track geometry survey conducted by the railroad do not necessarily require action before the next train; in a sense, the data is treated as "advisory" to the track inspector who then decides on the appropriate follow-up action. For defects that pose an imminent risk for derailment, such as wide gage, practice dictates that immediate action is taken. Because of the frequency of most automated inspections – anywhere from two or four times a year on a particular territory to monthly inspections at most – such follow-up is considered reasonable, given that the track inspector is able to observe the conditions from an inspection vehicle and decide upon appropriate follow-up actions.

FRA acknowledges that current practices and regulations may actually provide a disincentive for implementation of autonomous technology. With an increase in inspection frequency, railroads may be alerted to potential defects with great regularity, and follow-up inspections may prove costly and logistically difficult prior to the next train. Overall improvement in safety due to increased inspection frequency may justify a relief on reaction time or allowance for additional means of validation. Although difficult to commit to a plan at this stage in the development of the technology, one potential solution could involve re-evaluation of appropriate railroad response time and/or action to particular exceptions reported with an autonomous inspection system.

FRA and industry must work together to develop long-term strategic plan for implementation and usage of this technology. To that end, FRA is currently in the process of developing a "roadmap" for the implementation of autonomous inspection technologies so that it is in a position to not only be ready for the widespread use of this technology, but to promote the use of any approach that enhances safety with measurable results.

ROADMAP FOR IMPLEMENTATION OF AUTONOMOUS TECHNOLOGY

The vision of the FRA's roadmap can be summarized by the following phases of study:

- *Consideration of Risks Associated with Current Practices*: A basis for comparison of potential inspection and follow-up procedures must be established. A full evaluation of current practices based on automated inspection systems, visual inspection procedures, and autonomous track inspection systems employed to date should be conducted to determine risks associated with existing approaches. Results should lead to an assessment of top overall cost and risks associated with current inspection processes. Considerations should include:
  - Defect types, growth rates, and sizes pertaining to detection and safety criticality;
  - Probability of detection;
  - Inspection frequency;
  - Time associated with preventive action as well as corrective action;
  - Track time and manpower required for follow-up inspection.

- *Review Previous Approaches:* In order to avoid issues encountered during previous implementations of both automated and autonomous technology, a review of approaches applied in the United States and abroad should be conducted. The technologies considered should include, but not be limited to, those discussed in this paper (e.g. Amtrak's ARMS, FRA's ATGMS) as well as examples of other autonomous systems employed in the railroad industry that focus on vehicles as opposed to track, such as wheel impact detectors or hot-box detectors.

- *Determination of Appropriate Trial Processes:* Results from the aforementioned assessments should be considered to determine appropriate response time to events, changes in frequency of current inspections, and proper utilization of inspection data to guide and prioritize visual inspections.

- *Implementation of New Inspection Processes in Pilot Project(s)*: Trial processes, especially those with implication(s) to the Track Safety Standards, should be implemented within pilot studies that are established with host railroad(s) in cooperation with FRA. Projects of this nature are already in process as well as in the planning stages. The FRA's ATGMS has been in operation on Amtrak's Auto Train route in cooperation with both Amtrak and CSX Transportation. Future pilot programs are in the planning stages. Important considerations in a pilot study could include:
  - Review and analysis of results such as costs, service failures, slow orders, derailments (if any) and worst track conditions found during the trial;
  - Anecdotal evidence of problems which were allowed to continue because autonomous inspections were halted because too many defects had been found;
  - Estimates on the overall productivity of inspection processes.

As FRA Office of Research and Development formulates and refines this roadmap, it continues to reach out to industry and labor to assess and refine its approach.

CLOSING THOUGHTS

The development of autonomous inspection technologies is critical to improving efficiency and reducing the number of track caused derailments throughout the railroad industry. Industry and regulators need to take active steps to encourage the progress of these critical initiatives and acceptance of this technology. The ideas expressed in this paper are intended to provide guidance to railroads beginning to evaluate and employ this technology, and provide insight into the intentions of the FRA to foster adoption of this technology.

ACKNOWLEDGEMENTS

The authors would like to thank those in the industry who have adopted autonomous technology to date, as well as those that have supported the recent development of autonomous track geometry inspection. In particular, the contributions of Paul Steets and Michael Trosino of Amtrak, and Mr. Ronald Bright of CSX Transportation in the efforts to develop the FRA's ATGMS are greatly appreciated. The authors would also like to acknowledge the contributions to this paper of Mr. Kevin Kesler of the FRA Office of Research and Development.

REFERENCES

1. Department of Transportation, Federal Railroad Administration, "Track Safety Standards," Final Rule, 49 Code of Federal Regulations Part 213, June 22, 1998.

LIST OF FIGURES

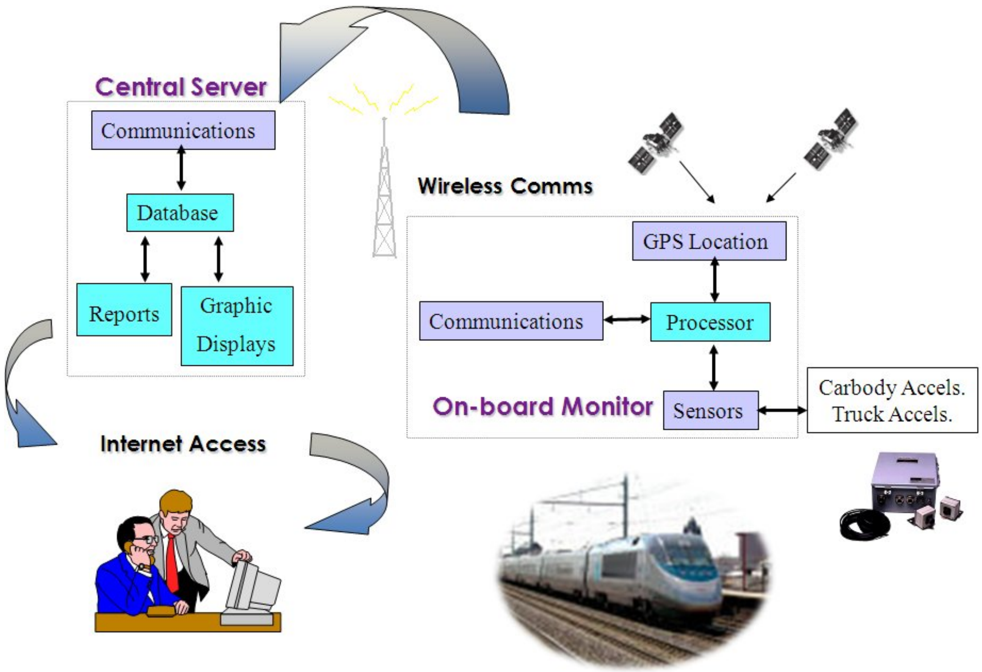

Figure 1. Concept Behind Amtrak's ARMS

On-Board ARMS Junction Box/Processor

Roof-Mounted GPS Antenna

Truck-Mounted Sensor

Figure 2. Vehicle-Mounted Components of Amtrak's ARMS

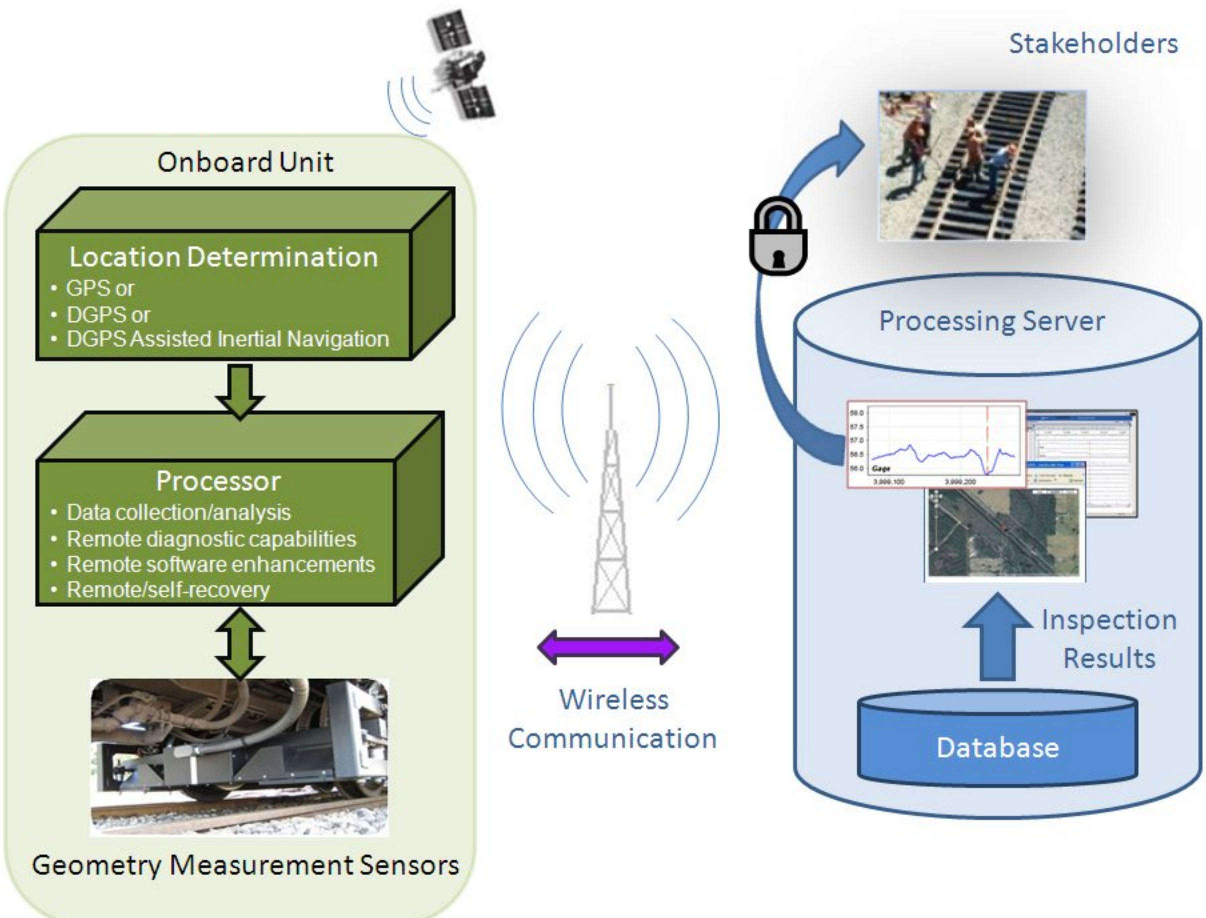

Figure 3. FRA's ATGMS Installation and Web-Based Reporting Application