



FEASIBILITY OF APPLYING MODEL-ASSISTED PROBABILITY OF DETECTION TO TRACK INSPECTION

SUMMARY

Model-assisted probability of detection (MAPOD) is a method for evaluating the effectiveness of inspection processes. It combines the results from a relatively small number of physical tests with more extensive results from computer simulation. Its application outside the rail industry is well documented. The Federal Railroad Administration (FRA), through a contract with ENSCO, Inc., has researched the feasibility of applying the MAPOD approach to the inspection of track flaws.

ENSCO researchers analyzed six types of track inspection to determine the feasibility of the MAPOD application. These covered a wide range of inspection technologies, including ultrasonic, radar, force and displacement transducers, and camera imaging.

The research team identified the factors that affect the probability of detecting flaws for each of the six types of inspection. In MAPOD analysis, these factors are either assessed experimentally with full-scale tests or analytically by computer modeling.

The team estimated the cost and practicality of testing and modeling for each of the six types of track inspection. This resulted in a ranking from most to least feasible for applying the MAPOD approach.

The team found ultrasonic rail flaw detection to be the most feasible type of track inspection for MAPOD application. This was mainly because models are already available for computer simulation and a test facility already exists at the

FRA's Transportation Technology Center (TTC) in Colorado.

The next step in this research is to develop a roadmap for applying MAPOD to ultrasonic rail flaw detection. The roadmap will guide the next phase of the project.

BACKGROUND

FRA has been researching methods for evaluating the effectiveness of track inspection technologies (Bruzek, Maymand, Drape, Smart, & Tunna, 2020). One recommended method is the analysis of the probability of detection (POD) of flaws. Typically, POD is calculated from the results of tests on samples with known flaws. The number of samples has a significant effect on the conclusions that can be drawn from the POD. Current best practice is to have at least 30 test samples for each flaw size.

MAPOD is a relatively new method that combines results from small numbers of physical samples with predictions from computer models. It was developed in the nuclear and aeronautical industries and has been documented in a U.S. military handbook (U.S. Department of Defense, 2009).

A key step in MAPOD analysis is deciding which factors that affect POD to assess with physical samples and which factors to assess with computer modeling. The cost and practicality of the two approaches guide this decision.



OBJECTIVES

The objective of this project is to examine the feasibility of applying MAPOD analysis to track inspection.

METHODS

The feasibility of applying MAPOD to six types of track inspection was examined (Table 1).

Table 1 – Track Inspection Types and Technologies

Inspection Type	Technologies
Rail Flaw Detection	Ultrasonics
Inertial Track Geometry Measurement	Displacement Transducers, Accelerometers, Gyroscopes, Camera Images, Lasers
Gauge Restraint Measurement	Displacement Transducers, Camera Images, Lasers, Pressure Sensors
Ballast Condition	Ground Penetrating Radar
Grade Crossing Profile Measurement	LiDAR, Camera Images
Joint Bar Condition	Camera Images

MAPOD requires identifying the factors that control the probability of detecting a flaw. These factors are then assessed either experimentally or analytically. Experimental assessment would involve physical tests with sample flaws. Analytical assessment would involve computer modeling of flaw detection.

The research team identified the following generic factors that could affect the POD of track flaws:

- Electronic noise
- Mechanical noise
- Image quality
- Flaw properties (e.g., shape, size)

- Human error
- Measurement speed and direction

The team then identified and analyzed the specific factors for each type of inspection to determine if they would be assessed experimentally or theoretically.

Finally, the team calculated the feasibility rating of applying MAPOD to each type of inspection using the following criteria:

- Model: Does computer software already exist, or does it need to be developed? If the latter, how difficult would that be?
- Data: Would the model need a small, medium, or large effort to create databases of input variables?
- Test Facility: Does a facility exist for physical testing or does one need to be created? If the latter, how difficult would that be?
- Experiment: Is the experimental effort small, medium, or large?

The result was a ranking of types of track inspection in terms of their feasibility of being analyzed using MAPOD.

RESULTS

Rail Flaws

Researchers found ultrasonic rail flaw detection to be the most feasible type of inspection for the application of MAPOD. The principal reason was that commercial software is available to model the effect of several factors, such as flaw shape and size and mechanical noise. This significantly reduces the need for physical tests, which would only be necessary to validate the model.

The model would require a large database of input variables, including rail cross-section and material; flaw type, size, orientation, and shape; and surface condition.

Human errors can arise with hand-operated ultrasonic rail flaw detection devices and affect the POD. For example, calibration errors can cause excessive false positives and false



negatives. Since human factors are difficult to model, they would be assessed experimentally. The Rail Defect Test Facility at TTC could be used for this purpose (Sheenan, 2018).

Inertial track geometry measurement is a potential candidate for MAPOD analysis. Although a model has not been developed for this purpose, vehicle-track interaction modeling software is available that could be used to create one. Such a model could then be validated with a limited number of tests on the high-speed adjustable perturbation slab track at TTC (Dick & Rakoczy, 2018).

Creating a database of inputs for modeling the inertial measurement of track geometry would be a manageable task. There is a well-defined set of track geometry deviations that could readily be used as inputs (Office of the Federal Register, 2013).

Gage restraint measurement would also require a model to be developed for MAPOD to be applied. A full-scale test facility would be necessary to validate the model. The test facility would need to cover the wide range of possible track components.

Joint bar condition by camera image would also require model development and a new test facility. A database for model input could be created from existing images of flawed joint bars.

Ballast condition by ground penetrating radar and grade crossing profile measurement by LiDAR were found to be the most challenging candidates for MAPOD analysis. Due to the wide range of ballast conditions and crossing profiles, they would both need large databases of model inputs and extensive test facilities. It is possible that ultrasonic testing software could be adapted for radar. However, significant effort would be required to develop a LiDAR model.

CONCLUSIONS

Ultrasonic rail flaw detection is currently the most feasible type of track inspection for

MAPOD analysis. Other types of inspection need models to be developed, and many don't currently have full-scale test facilities.

While the MAPOD approach reduces the need for experimental results, it does require significant effort to create databases of model inputs.

FUTURE ACTION

FRA is pursuing the development of a roadmap for applying MAPOD to ultrasonic rail flaw detection. This roadmap will be the subject of another Research Results report.

Once the roadmap is complete, FRA will complete a full MAPOD analysis of ultrasonic rail flaw inspection using commercially available software. This will demonstrate the approach in the railroad industry and will serve as a guide for the application of MAPOD to other types of railroad inspection technologies.

REFERENCES

- Bruzek, R., Maymand, S., Drape, G., Smart, K., & Tunna, J. (2020). [Methods for Evaluation of Track Inspection Technology Effectiveness](#) [DOT/FRA/ORD-20/03]. Washington, DC: U.S. Department of Transportation.
- U.S. Department of Defense. (2009). [Nondestructive Evaluation System Reliability Assessment](#) [MIL-HDBK-1823A]. ASC/ERNS.
- Dick, S., & Rakoczy, A. (2018). [Slab Track at Facility for Accelerated Service Testing: Performance and Serviceability](#) [DOT/FRA/ORD-18/02]. Washington, DC: U.S. Department of Transportation.
- Office of the Federal Register. (2013, March 13). Code of Federal Regulations, [Title 49 Part 213 – Track Safety Standards](#).
- Sheenan, R. (2018). [Recharacterization of Rail Defect Test Facility at the Transportation Technology Center](#) [DOT/FRA/ORD-18/12]. Washington, DC: U.S. Department of Transportation.



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