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Optimal Locations of Railroad Wayside Defect Detection Installations

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Summary

The University of Illinois at Urbana-Champaign has developed a network optimization model that selects cost-effective installation sites for a wayside defect detection system over a railroad network. This work, sponsored by the Association of American Railroads and CSX, can be used to evaluate potential locations for wayside detector systems, such as Acoustic Bearing Detectors, which are used for car component failure prediction and maintenance planning.

A series of case studies with empirical data illustrate the usefulness of the model. The computational results show that the optimization problem can be solved efficiently with the custom-designed algorithm developed in this work. The model, solution technique, and the software have the capability of being applied to full-scale railroad networks at regional or national levels. Additionally, there are a variety of ways that railroads can use this model and algorithm to help them invest in wayside inspection technology efficiently so as to maximize the safety and economic benefits of these technologies.

The optimization algorithm was applied to solve for a range of 1 to 20 installation locations that maximize the number unique railcars inspected. Compared with the existing installations on this railroad company's network, solutions from the covering model (with the same number of installations) were shown to improve the inspection benefit by more than 40 percent.

The objective of this examination is to maximize the total inspection benefits possible under any given investment budget. A rigorous mathematical programming model was developed to systematically select the best installation locations. Efficient solution techniques were developed to solve the problem despite the huge number of parameters usually associated with railroad networks. A stand-alone computer program was developed that can be used directly by any railroads to analyze any network. The model has the flexibility to accommodate many types of detectors and differing objectives for each. For example, a railroad may want to site wheel impact load detectors on coal service routes. But, it may want to locate automated safety appliance inspection systems on general freight routes. The model has the ability to select locations which optimize car inspection opportunities system wide or for specific traffic types.

Railroads have been using wayside inspection technologies for many years and recently new technologies are proliferating. Efficient deployment of these technologies is important if railroads are to derive the maximum benefit from their investment. The project was funded under the auspices of the AAR Technology Scanning Program.

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INTRODUCTION

Millions of dollars have been invested to install wayside detectors to monitor the health and performance of railcars. New detector types are to be deployed to benefit the railroads by helping reduce derailments and damage to equipment and infrastructure. In general, these new technologies go beyond detecting problems for which catastrophic failure is imminent. They are looking for irregularities in performance of a component that suggest some type of maintenance may be needed in the future. The greater sophistication and capability of these systems often means higher cost. It is imperative that capital for such installations be allocated in a manner that will maximize the effectiveness of their use. The key question here is the trade-off between inspection benefits (e.g., the number of railcars inspected) and investment costs (e.g., the number of installations).

The following example illustrates the optimization problem in consideration. Figure 1 depicts a small railroad network, where the lines represent the paths of different railcar flows, and the labeled nodes represent the candidate locations for installations. There are four flows (1) the blue flow goes from Seattle, Washington to St. Louis, Missouri, through locations 1, 3, and 5, (2) the green one from San Francisco, California, to New York City, New York, through locations 2, 3, and 4, (3) the red flow from New York City to Minneapolis, Minnesota, through location 4 and 6 and, (4) the yellow flow from St. Louis to Minneapolis through locations 5 and 6. The problem is to find two (or any other number) installation locations out of the six candidates that can inspect the maximum amount of flows. For this small problem, it may take only a little effort to find out that installing detectors at locations 3 and 6 can inspect (cover) all four flows. That is the optimal solution.

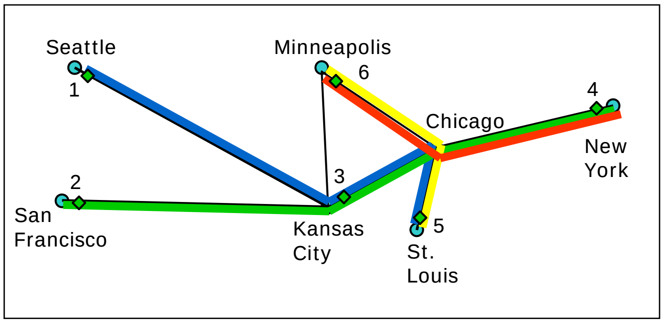

Figure 1. A Detector Location Problem Example

This example only involves four flows and six candidate locations. In practical cases, there are millions of shipments/railcars and tens of thousands of candidate locations. The optimization problem is much more complicated and the solution is much less obvious, as the problem belongs to a class of NP-hard combinatorial optimization problems that are the most difficult type of problem to solve.

The University of Illinois at Urbana-Champaign with funding from the Association of American Railroads and CSX conducted this research. The main goal was to handle the large-scale detector location optimization problem in a systematic manner by formulating a network design model and designing suitable optimization techniques to solve the complex problem efficiently and accurately.

METHODOLOGY

The model systematically selects the optimal locations from a given set of candidate locations, while each location can accommodate one and only one of multiple types of detectors. Each detector type and location combination has a characteristic installation cost (e.g., equipment, supply, and maintenance). Overall, the installation costs for all detectors at all locations cannot exceed a total budget. Meanwhile, each installation will bring a certain amount of benefits by inspecting a subset of the railcar traffic. These subsets of railcars, however, are mutually inclusive in general (e.g., two detectors may be inspecting the same set of railcars), thus the busiest locations (i.e., with highest traffic) cannot simply be selected without considering their interactions. The objective of the optimization model is to find the best combination of locations that maximizes the expected total inspection benefits.

Analysis of all the railcars operating on the entire U.S. railroad network, or even on one of the major Class I railroads, represents a huge computational effort. There are approximately 1.5 million railcars in service, and one national rail network model, Princeton Transportation Network Model (PTNM), has over 50,000 nodes. The amount of data with these dimensions poses formidable computational challenges as the network model is a typical integer program and is known to be NP-hard. To address these challenges, a Lagrangian-relaxation algorithm, which is known to solve this type of problem efficiently, is developed together with advanced data storage (e.g., sparse matrix) and preprocessing techniques.

EMPIRICAL RESULTS

A random sample of network locations and railcar trips were selected for one Class I railroad and loaded into the railroad network model. Each railcar was identified as a distinct flow unit and the set of candidate locations includes origins, junction, and termination locations of the railcar flows on the railroad network.

The locations where each railcar originates, passes by, and terminates can be identified using a railroad network flow model, such as the PTNM. In PTNM, the NET3 numbers indicate the individual nodes or locations on the network. In our case study, we identified 8,920 individual railcars traveling around the network and 1,820 candidate detector locations. Figure 2 illustrates candidate locations. Figure 3 shows the 10 optimal candidate locations.

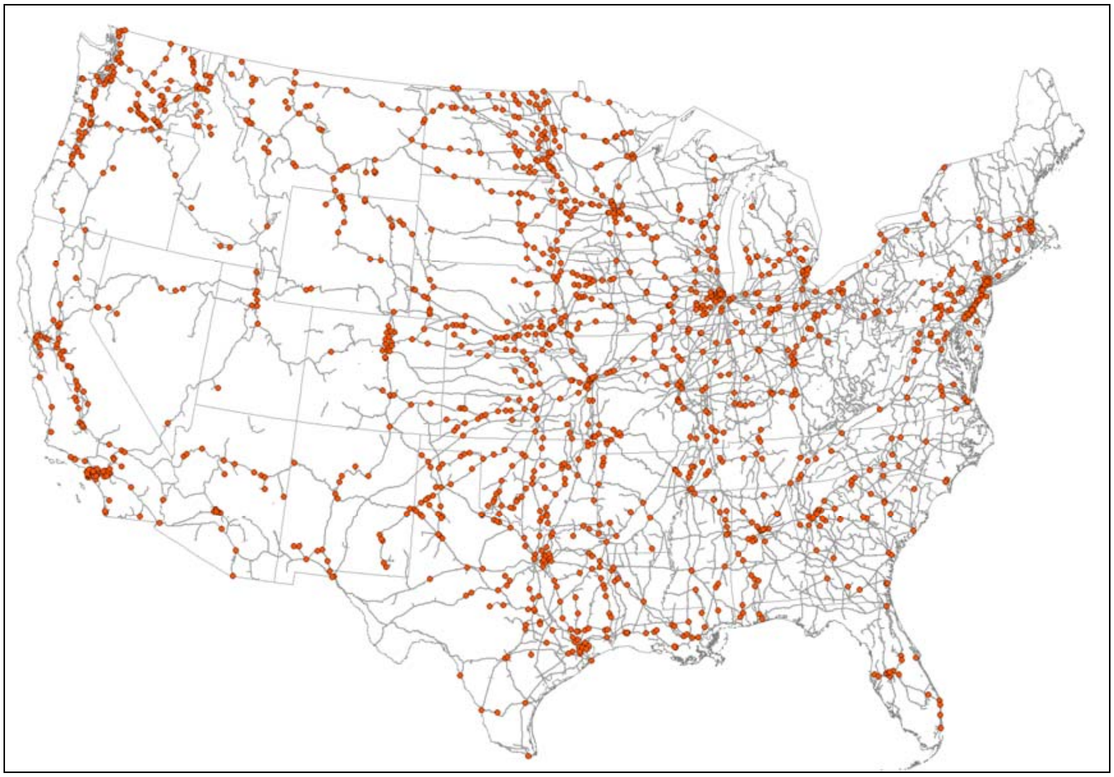

Figure 2. The Railroad Network Example Candidate Locations

Figure 3. The Railroad Network Example Optimal Locations

In this rather simple problem, TTCI and CSX considered installing one type of wayside technology to maximize the total number of distinct railcars inspected in a year. The 10 best locations were obtained for our sample of railcar traffic (Figure 3), in which 4,951 cars (or 57 percent of the total) are detected.

Only four out of the top 10 optimal locations are actually among the top 10 busiest nodes. If detectors are placed at the 10 busiest locations, 4,160 cars would be detected in a year, which is 19 percent lower than the optimum. This simple example clearly demonstrates the importance of optimizing detector locations as a combination at the network level.

TTCI and CSX also collaborated with a Class I railroad to run the model with empirical data of its railroad network (nodes, links) and traffic (railcar shipment schedules) in 30, 90, and 120 days. The optimization algorithm was applied to solve for a range of 1 to 20 installation locations that maximize the number unique railcars inspected. Compared with the existing installations on this railroad company's network, solutions from the covering model (with the same number of installations) were shown to improve the inspection benefit by more than 40 percent.

SOFTWARE DEVELOPMENT

A stand-alone computer program was developed to solve large-scale detector location optimization problems efficiently and accurately. This software optimizes the placement of wayside technology installations to maximize the number of inspected distinct railcars, for any railroad network and any given number of installations (budget). If the railroad does not have full records of the locations on the route of a railcar shipment, an optional shortest path algorithm will be implemented to fill the gap. The software finds and displays the best set of locations that inspect the maximum number of railcar flows. It can also determine the subset of railcars that were inspected by a (any) given set of locations. For more information about this software, see Reference 2.

DISCUSSIONS AND CONCLUSIONS

Wayside inspection technology is already widely used and critically important to railroads. Meanwhile, the diversity and usage of this technology is expanding rapidly and its importance will become even greater. It is important that railroads maximize the efficient deployment of these technologies by placing them in locations where they can derive maximum value from the information they provide. The benefits of such installations come from monitoring railcar condition and detecting defects before they cause a delay or an accident. This work presents a network design model to optimize the placement of wayside detectors.

Installation of existing technologies is likely to take a number of years and as new technologies are developed, railroads will need to know the optimal deployment locations and schedules for these. The model can be used to identify the optimal ordering of the installation of detectors over a multi-year period, thereby helping ensure that they receive maximum benefit in the shortest amount of time. Also, as traffic patterns change, installation of new detectors should reflect these changes. As new traffic data or projections become available the model can be rerun to check and see if existing detectors should be supplemented by new installations, or possibly moved so that the railroad continues to derive maximum benefit.

The same approach to a railroad optimizing its installation locations can be applied at the national level. Since all railroads have an interest in maximizing the detection and inspection of freely interchanged rail cars, there is a collective interest in optimizing detector deployment overt the entire rail network.

A more specialized application of the model's potential use involves particular types of inspection technology that are particularly important for certain types of cars or traffic. For example, certain railcar types are particularly susceptible to problems with the ability of their trucks to steer well in curves.

Finally, the model may have utility in helping railroads assess performance goals for their overall inspection activity. Under the status quo they have deployed wayside inspection equipment at various points around their systems based on a variety of criteria and are receiving information that they find useful. The model can be used to provide an objective metric of the potential performance that they can compare to the performance of their current installations. In addition, the model can be used to guide further, new installations in an optimal manner.

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