Extended Abstract: Periodical Rail Inspection Scheduling in Railroad Networks

Fan Peng, Yanfeng Ouyang and Kamalesh Somani

1. Introduction

Every year, North American railroads spend millions of dollars on rail inspection. A fleet of rail inspection teams (including inspection vehicles and associated crews) travel on the railroad network and examine rail tracks for external and internal rail defects (such as kidney defects, wheelburn defect, head checking and squats) using visual inspection and technologies such as induction and ultrasonic devices (Cannon et al., 2003). According to the Federal Railroad Administration (FRA) Office of Safety Analysis (2010), track defects have become the leading cause of train accidents in the United States. Among the 1,890 train accidents happened in 2009, 658 (or 34.81%) were caused by track defects, resulting in a total reportable damage of $108.7 million. Therefore, it is very important to optimally schedule the rail inspection so that the rail defects can be identified and repaired in time.

In practice, the railroad network is divided into hundreds of segments for the sake of rail inspection. Every segment should be inspected periodically at a certain frequency (which generally varies from once a few weeks to once a year) to ensure the safety of train operations. In this paper, we call each inspection activity a “task”. A rail inspection schedule includes the assignment of tasks to inspection teams as well as the start times of the tasks such that all required inspection frequencies are satisfied. It should also satisfy a variety of other business constraints such as geographic preference, non-simultaneity and time window constraints. The scheduling horizon is normally short (e.g., a few weeks), while the schedule is updated frequently (sometimes daily) to address unexpected events (e.g., the delay of a task or the breakdown of a vehicle). Occasionally, long-term scheduling is also needed for resource allocation purposes (e.g., to determine the optimal number of inspection teams and to balance the workload throughout the year).

Practical RISP instances are usually very large-scale and complex, involving hundreds or thousands of tasks, tens of maintenance teams and thousands of business constraints. Current practice of the railroad industry mostly relies on the experience and judgment of experts. The solution process usually takes a long time but the solution quality may remain unsatisfactory. This paper, therefore, proposes a mathematical model and solution algorithm to systematically and effectively solve RISP.

The results from the proposed approach can help the railroads improve their safety and operational efficiency.

2. Literature Review

Very limited research has been done on problems similar to RISP. Morales et al. (2008) studied a similar geometry inspection scheduling problem which addresses not only the inspection frequency requirement, but also crew change point constraints and track restrictions (e.g., travel direction requirements, sharp-turn restrictions, and multiple tracks) for rail-bound inspection vehicles. The inspection territory of each vehicle was pre-determined, and the model scheduled only one vehicle at a time. The model enumerated all possible day routes as decision variables, and could usually be solved by a commercial integer programming solver within 12 hours. What-if analysis was used to reassign territories among inspection teams in order to balance workload and improve the solution. Routine track maintenance activities, such as rail grinding, are also subject to certain frequency requirements. Derinkuyu et al. (2010) presented a rail grinding scheduling problem and developed an optimization model whose objective was to minimize the deviations of grinding activities from a given set of desired maintenance frequencies. Retharekar and Mobasher (2010) presented a preventive maintenance scheduling problem. Constraints related to various factors such as train schedules and desired maintenance frequencies are considered. Heuristic algorithms were developed in both studies but the details are not disclosed.

3. Model Formulation

We proposed a vehicle routing problem (VRP) based model for RISP. Multiple types of side constraints are considered. Periodicity constraints require all segments to be inspected periodically at certain frequencies. Non-simultaneity constraints require certain pairs of tasks (e.g., those in the same subdivision or involving the same railroad human resources) not to be performed simultaneously in order to avoid conflicts. Time window constraints require tasks to be performed within certain time windows, in order to avoid exogenous conflicts caused by geometry inspection activities or capital maintenance projects. Preference constraints require certain tasks not to be performed by certain teams, in order to avoid the crew members working in unfamiliar/undesired territory.

4. Algorithm

We proposed customized heuristics to handle the complex RISP based on an "incremental horizon" approach. The basic idea is as follows. Suppose the original problem has a total scheduling horizon $[0,\hat{U}]$. Instead of solving the whole problem at once, the algorithm solves a smaller version with a short horizon $[0,U]$, where $U<\hat{U}$. Once a solution is obtained for this smaller problem, we increase U incrementally and solve the extended problems until $U=\hat{U}$. It turns out that this solution approach is able to improve the solution quality.

Figure 1 illustrates the proposed algorithm framework. The algorithm typically starts with a short scheduling horizon (one to three weeks) and an empty set of tasks. It first generates a task for every segment which does not have an unscheduled task (i.e., a task not assigned to any team). A greedy algorithm and a task-interchange algorithm are then applied to add the newly generated tasks to the schedule and optimize the schedule. The algorithm terminates if all stopping criteria are met, i.e., (i) $U=\hat{U}$, (ii) no new tasks are generated in the current iteration, and (iii) the current solution is not improved in the current iteration; otherwise the algorithm increases the scheduling horizon U by a certain value (one to three weeks) if $U<\hat{U}$, and repeats the process of generating tasks and applying heuristics.

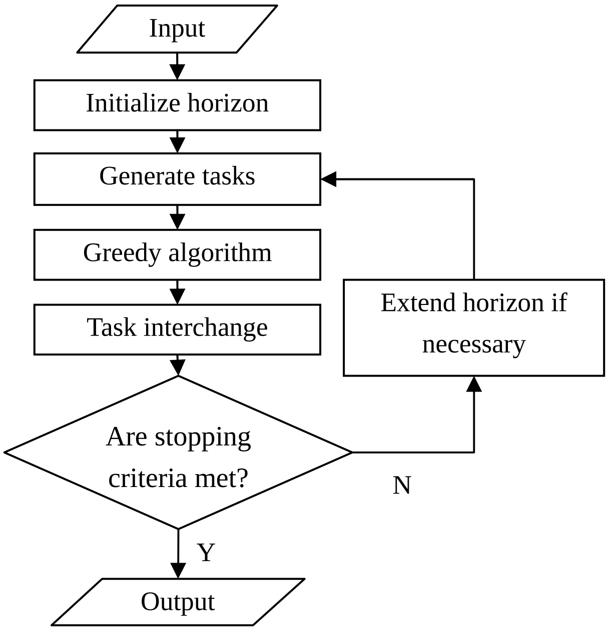

Figure 1. Algorithm framework of rail inspection scheduling.

5. Case Studies

The proposed model and algorithms are applied to a full-scale RISP instance in a Class I railroad company. The algorithms are implemented in the Microsoft Visual C# environment on a personal computer with 2.66GHz dual core CPU and 3 GB RAM.

The first case study is conducted for a weekly scheduling problem instance in some week of a recent year (referred to as “Year A” from now on). This problem instance contains about two dozen of teams and more than 700 segments. The scheduling horizon is 8 weeks, and every segment has from 1 to 4 tasks to be scheduled. The solution time of the proposed algorithm is less than 1 minute. The model solution is compared with the manual solution provided by experts from the company. The comparison shows that the model solution has a far better performance in terms of all major statistics, i.e., overdue percentage, travel distance, and non-simultaneity constraint overlapping duration.

The second case study is conducted for a long-term planning instance. The scheduling horizon is one year, and it starts from the summer of Year A. For such a long scheduling horizon, some segments may be inspected more than 12 times within the horizon. Thus the number of variables is much larger. The model is run for four different scenarios to perform what-if analyses: (a) using N (i.e., the current number of teams used by the railroad) teams with geographic restrictions (i.e., preference constraints which require a team to only work on certain segments), which is the current industry practice, and using (b) N, (c) N-1 and (d) N-2 teams without geographic restrictions. The model is able to obtain the solution within one hour for each of the four scenarios.

The results show that the model is able to eliminate almost all overdue percentage outside the threshold within the year. If the railroad keeps N inspection teams but remove the geographic restriction of them, most overdue percentage outside the preferred interval can also be eliminated. If the railroad remove one or two inspection teams from the workforce, the percent of overdue outside the preferred interval will increase, but there is still little overdue outside the threshold. So there is a tradeoff between the number of inspection teams and the overdue percentage. If the costs of extra teams in scenarios (a) and (b) can justify the reduced overdue percentage compared to (c) and (d), the railroad should probably keep all teams; otherwise it can reduce the number of teams.

6. Conclusion

This paper studied the rail inspection scheduling problem by proposing a VRP model formulation with multiple types of complex side constraints, such as periodicity constraints and discrete working time constraints. An iterative solution algorithm, which includes a constructive heuristic and a local search method, is developed in an incremental scheduling horizon framework. The proposed modeling and solution approaches have been applied to real-world problem instances for both short-term scheduling and long-term resource planning. For short-term scheduling, our numerical case study has shown that the proposed approach is able to obtain a much better solution than the state-of-art manual procedure. For long-term planning, which cannot be solved manually, we conducted what-if analyses to draw managerial insights and help the railroads improve their operational efficiency.

References

1. Cannon, D.F., Edel, K.-O., Grassie, S.L. and Sawley, K. (2003). Rail defects: An overview. *Fracture & Fatigue of Engineering Material & Structures*, 26(10), 865–886.
2. Derinkuyu, K., Balakrishnan, A. and Morales J. (2010). Scheduling rail grinding operations. Presented in *INFORMS Annual Meeting 2010*, Austin, TX.
3. Federal Railroad Administration Office of Safety Analysis. (2010). Available online at http://safetydata.fra.dot.gov/officeofsafety/. Accessed on December 5, 2010.
4. Morales, J., Balakrishnan, A. and Li, G. (2008). Optimal Routing of Geometry Cars. Presented in *INFORMS Annual Meeting 2008*, Washington, D.C.
5. Retharekar, A. and Mobasher, A. (2010). Routing and scheduling preventive railway maintenance with predetermined desired reliability. Presented in *INFORMS Annual Meeting 2010*, Austin, TX.