A Modified Shifting Bottleneck Procedure for Train Scheduling in the UK

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Introduction

Due to the increasing volume of railway traffic and the high expenses of construction or modification of infrastructure, train scheduling is employed to ensure the best usage of the existing capacity in offline and online mode. There has been increasing interest in the train scheduling problem recently and job shop scheduling techniques have been exploited in some of these studies [10, 9, 6, 7, 3, 2, 4]. This paper aims to achieve further developments including refinements to existing models to consider more realistic and detailed constraints in the UK railway industry. Moreover, we develop a new solution method inspired by the successful results of the shifting bottleneck procedure to solve job shop scheduling problems. The proposed method is implemented on a real-world case study based on the UK railway network that is dense and complex.

Problem definition

This paper addresses the train scheduling problem at the micro level including detailed information about the tracks and train movements. We base our experiments on a bottleneck area in the South East of the UK where the network has a complicated structure including various junctions and stations. Whereas earlier research investigates networks with only passenger or only freight traffic, our network has mixed traffic including train priorities. The aim is to define entry times and the order of trains on blocks for predetermined routes to get from origin to destination. Hence, a conflict-free schedule is created by timing and ordering trains at junctions and stations in order to improve the utilization of the current infrastructure and capacity. In the case of disruptions, the same scheduling technique can be applied for real-time traffic management when the solution method is fast enough. Moreover, the possibilities of adding additional services in the area can be investigated for long term planning by using the same approach. Thus, the objective is to minimize the total weighted tardiness in order to avoid delay propagation, subject to a set of operational and safety constraints.

Problem Formulation

There is a strong similarity between train scheduling problem and the well-known job shop scheduling problem. Hence, a train traversing a block is analogous to a job being processed on a machine. We model the job shop problem first as a Mixed Integer Linear Programming (MILP) to minimize the total weighted tardiness of the jobs, subject to the following sets of constraints: running time, dwell time and headway constraints. Another set of constraints is added to consider a blocking job shop problem which forces jobs to remain on a machine after their completion until the next machine becomes available. Modelling the conventional job shop scheduling problem with a disjunctive graph [8] is quite popular in the literature. As a modification of the disjunctive graph, the alternative graph [5] addresses the no buffer capacity limit between consecutive machines. We also use a modified version of the disjunctive graph to show operational constrains in the train scheduling problem.

Solution Method

The train scheduling problem is a very large and complex combinatorial problem. Thus, it seems to be more appropriate to use heuristic methods which produce the most promising results for the job shop scheduling problems. The shifting bottleneck procedure by Adams et al. [1] is known to be one of the most fruitful methods for solving the job shop scheduling problem. A modified heuristic method based on the shifting bottleneck procedure is proposed for train scheduling problem. This new approach differs from the conventional approach in finding the bottleneck and solving the single machine problem. Also, it has a new additional re-optimization step to re-sequence the earlier scheduled machines. The code is developed in MS Visual C++ 2010 and tested against a First Come First Served (FCFS) dispatching rule for the UK railway case study. The computational experiments show promising results for the proposed method regarding the solution quality and computational time.

Conclusion

In the past few decades, the rail industry has benefited from the advances in technology and applications of operations research methodologies. In this study, the train scheduling problem is formulated as a modified job shop scheduling problem with additional constraints. We propose a new algorithm based on the shifting bottleneck procedure. The performance of the suggested algorithm is compared with the most commonly used FCFS dispatching rule. The experimental results are reported for a real-world case study in the UK railway network where instances offer detailed data for microscopic train scheduling.

Acknowledgements We thank School of Management, previous LASS faculty of the University of Southampton and LANCS Initiative for partially funding and supporting this project. We are also grateful to Southeastern the passenger operator for providing data.

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