Cost Optimization for the Capacitated Railroad Blocking and Train Design Problem

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1 Introduction

This paper considers the combined problems of railroad blocking, train design and train assignment as observed in the railroad industry. The problem of railroad blocking deals with finding the least cost paths for a given set of shipments over an entire railroad network. Blocking is defined as an activity where a set of shipments arriving at or commencing from a certain node station and departing to another particular node station, or further, are grouped together and sent across as the same train to minimize costs and exploit economies of scale. This problem has marked similarities with the airline scheduling which operates flights across a predetermined hub and spoke network. The problem considered here not only necessitates determining the "right" hubs and "right" trains to be scheduled on the network, but also scheduling the shipments on appropriate trains between the hub station yards and spoke station yards so that the overall costs are minimized.

The motivation for the problem comes from a competition conducted by INFORMS Railway Application Section in 2011. In the problem considered by us, a network comprising sets of nodes, arcs and a set of shipments with their origin and destination nodes are given. Expenses related to operationssuch as the cost of car travel per mile, cost of train travel per mile, cost of starting a train, cost of grouping (also referred to as classifying or blocking) shipments at an intermediate station of a train, cost of train imbalance, cost of crew imbalance and the cost of a missed car that is not transported are also given in the problem definition. It is also required that each train path completely overlaps one or more crew segments. Crew segment between two nodes will also always follow the shortest path between those two nodes. Thus a train cannot run on a section which is not on the path of a crew. Train imbalance is defined as the imbalance generated due to the difference between the number of outgoing and incoming trains at a node. Total train imbalance for the network is computed as the sum of imbalances at every node. Crew imbalance is generated due to the fact that a crew operates on a segment, but cannot find an operational train to return to their base. In addition to these considerations, there are specific constraints such as the maximum number of trains that a shipment can travel on, the maximum number of blocking (or classifications or work events – as referred in the problem statement) allowed for each train, the maximum number of trains allowed on any arc and the limitation on the maximum train length and tonnage.

The main objective of our efforts would be to find a cost minimizing set of feasible trains that operate on one or multiple crew segments completely. We would also need to determine the least cost assignment of shipments to these trains. We are given two data sets to test the performance of our approach and produce results. While we make every effort to find the best cost optimized solution for these two instances, our algorithmic approach should be as generic as possible so that the performance is reasonably good for various scenarios. Our report is organized with a brief survey of existing literature on this and other similar problems, followed by a description of our algorithm to this problem, and finally conclusion with the results for the two data instances.

2 Literature Survey

It must be noted that the operations research techniques in railroad industry has been in application for several decades. Some of the problems such as train timetabling, locomotive assignment, refuel point location scheduling, platform assignment etc. have been well studied in the literature. The problems of railroad blocking, train design and block-to-train assignment are one of the most basic, and consequently extensively researched topics as well. One of the earliest works in this area was done by [1] where blocking is formulated as the arc-based multi-commodity flow problem. The most recent literature on railroad blocking is that of [2] and on Block-to-Train assignment is published by [3].

The railroad blocking problem considered by [2] identifies a classification plan for all shipments at all station yards in the network to minimize the total shipment cost. This is referred to as a blocking plan. The railroad blocking problem can be mathematically formulated as a very large-scale, multi-commodity, flow-network-design and routing problem with several million decision variables. To apply in a practical context, [2] implemented an algorithm using a technique that is referred to as very large-scale neighborhood (VLSN) search that is able to solve the problem to near optimality after a few hours of computation. The algorithm starts with a feasible solution and then progressively improves this solution by reoptimizing the blocks made at one node over a repeated, iterative process. They have also shown that it is easy to add side constraints to this algorithm.

[3] consider the problem of block-to-train assignment (BTA) and provide two formulations for this problem: an arc-based formulation and a path-based formulation. The path based formulation is reported to better handle practical constraints. Exact and heuristic algorithms based on the path-based formulation are proposed in this paper. The MIP formulation is based on set-covering approach where all shipments are assigned to a single path that is covered by one or more trains. Exact algorithms – for both apriori path generation and dynamic path generation – are reported to be successful for only very small problem instances. For the larger instances, the paper suggests a greedy algorithm and also a Lagrangean heuristic – both of which have reasonable run times.

It is clear from the literature survey that published research work on the specific problem considered by us is non-existent. While block creation and block-to-train assignment problems have been studied, the problem has not been studied jointly with crew segment path constraints. One of the major contributions of this work is to solve the joint block creation and train design problems with crew segment path constraints. We also consider other complexities inherent in a practical problem, such as train and crew imbalances which have usually been ignored in the literature. We will now analyze the problem and suggest methods to solve.

3 Solution Approach

It is very complex to build one model that can optimize the costs associated with crews, shipments, trains as well as imbalances associated with them in an integrated manner. The approach that we would take to solve this large-scale problem is to break it up and solve it in parts. As a first step, we will determine the least cost path for each shipment. Since the paths themselves are composed of a sequence of arcs, we can also find the number of trains that must be run on each arc subject to the capacity (tonnage and length) constraints. While shortest path algorithm (Dijkstra's algorithm) is easy to solve and simple to implement, they are not optimal when certain arcs or nodes have capacity constraint. We can use the same multi-commodity flow mixed integer linear program (MILP) formulation with some adaptation as suggested by [3] (as well as [1]) to find the shortest path for shipments and the number of trains that must be run on each arc of the capacitated network.

While we do not describe the parameters, decision variables and the mathematical model in this extended abstract, it must be mentioned that the mathematical model developed by us can not only find the shortest paths for the shipments on the constrained network, but also capable to identify certain constrained arcs where shipments would need to be blocked. The output of the model gives shipment paths along arcs and a set of shipments that must be blocked together on certain paths. This extensive list gives our first trains and every shipment is supposed to follow its own train.

The next step is to assign crew segments for these train paths. To accomplish this, we formulate a set-covering MILP formulation that covers each train path entirely with minimal cost crew segments. The crew imbalances are also taken care of within this mathematical formulation.

The last step is to combine these crew-feasible trains to create fewer trains with lesser imbalance. To minimize the train start cost, two or more of these crew segments may be merged. We suggest employing an intuitive heuristic for this purpose. Since there is a capacity on the number of swaps for every shipment, we first find the shipments that are linked by crew segments beyond one more than the allowable swaps (since swap is a transfer, the number of trains that a shipment is transported can be one more). These crew segments are merged on a priority basis as the solution would otherwise be infeasible. The next set of crew segments considered for merger is the ones with the highest number of contiguous shipments. The process of merging crew segments is continued till no two segments are mergeable due to the constraints. While merging the crew segments, the following criteria must be always maintained:

- Last node of previous segment and first node of next segment must be same
- The number of intermediate work events on the new (merged) train path must be within the allowed limit
- Number of swaps for every shipment is kept below the allowed threshold

The above sequence of steps would guarantee satisfactory solutions for most problem instances. However this algorithm has two limitations. Firstly, it can be applicable for only small problem instances as the run time of MIP models with several hundred nodes and arcs is seldom within reasonable limits. Secondly and more importantly, the algorithm is performed sequentially and by the last step, all solutions could be found to be infeasible. Thus it gives need for us to develop an alternative simplistic algorithm which may output sub-optimal solutions, but ensure that at least one feasible solution is found. We developed and implemented a greedy algorithm that could easily solve large problem instances and serve as a benchmark for comparison with the three-stage model.

4 Implementation and Results

We used two different data sets. The smaller data set had 239 shipments, 94 nodes, 268 arcs and 308 crew segments. The larger date set had 369 shipments, 221 nodes, 588 arcs and 308 crew segments. There are some cost elements such as crew imbalance penalty ($600), train imbalance penalty ($1000), train and car travel cost per mile ($10 and $0.75 respectively), work event cost ($350), trains start cost ($400), missed cost per railcar ($5000) and blockswap cost for each node (varying between $30 and $100). The multi-stage MIP stage model produced excellent results and the run time usually ranged from 20-30 mins. The run times were less - about 90 and 200 seconds - using the greedy algorithm. The greedy algorithm also improved by 1-3% when allowed to run longer iteratively for longer times. However the quality of solution obtained from the greedy algorithm was 8 – 12% worse than the one produced by the mathematical model.

References

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