An adaptively relaxed constraint satisfaction approach for a demand responsive freight rail timetabling problem

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In a demand responsive rail service for transporting freight containers, there may be a large number of potential timeslots over the operational period, e.g. one week, that services may be timetabled to run [1]. This is a transportation problem with many hard and soft constraints. Using the constraint satisfaction approach, the main set X of variables would be binary decisions of whether to operate a service or not in each potential timeslot. When these main variables are set, how each customer is or is not served by each timetabled trip would be determined. However, it may help the constraint satisfaction search to include another set Y of binary variables of whether a customer is served by each potential timeslot. A constraint-based local search approach inspired by SAT local search [2, 3] is presented to solve this constraint satisfaction problem. The key feature of the algorithm is that variables from both X and Y may be chosen for trials of flipping their binary values, but the propagation of consistency may not be carried out fully all the time. At the beginning, constraint propagation is only carried out for within each of X and Y but not across the two sets of variables. This promotes wider exploration of the search space. After some iterations, the trial history is analysed. Some variables may appear to have high probability of having certain values, and they will be fixed for a number of iterations. At that point, consistency between the X and Y variables involved are enforced, leading to intensified exploitation of the neighbouring search space.

For the freight rail timetabling problem, decision variables X and Y may take several different values across the set of feasible timetables. Thus, it is very difficult to predict a good consistent value for the variables. However, when the problem is severely constrained and has few feasible solutions, it may well be that some variables would take more consistent values in all the feasible solutions during the search. Once a variable has been selected, the search algorithm has to choose a value that is likely to lead to a smaller total degree of hard violation in a complete assignment. In our search algorithm, two variables are considered at each trial iteration. The first variable is chosen in a violated constraint and considered as a variable of interest, the second variable is randomly selected from the search space and used for a comparison. Flipping the first variable might result in a reduction in total hard violation. However, it might be that flipping the second variable would result in even more reduction in the constraint violation. Therefore the flipped value of the first variable is not accepted and the unflipped value is recorded for the lowest total hard violation. Clearly, the interdependency of the variables implies that the

effect of the value chosen for any particular variable in isolation is uncertain. This observed inconsistency is taken to be a result of the uncertainty or random behaviour on the part of a given value choice decision. Therefore, at each flip trial, the algorithm is enforced to select the choice of value with lowest total hard violation (disutility) for a variable of interest. We derive a choice probability by assuming a joint probability distribution for the two random disutilities. We use this choice experimental design to formulate the predictive choice model [4] in order to predict a good value for the variables and to use these predicted values to fix and enforce the consistency between X and Y variables.

The algorithm presented is tested on a freight rail timetabling problem from the eastern-line container rail service, the Royal State Railway of Thailand. Over a hundred customers and several thousand containers are served by rail there. At present, the Royal State Railway of Thailand provides a weekly fixed schedule in which a certain number of trains are provided in fixed departure timeslots. However, in practice, the RSRT's schedule may not be fixed at the same service level every day. This is because the rail carrier may cut down the number of train services within a short notice if the train supply is considerably higher than the customer demand. This is done by delaying some customers' departure times according to its demand consolidation strategy. The real life data is colleted form four successive weeks with 184 shipping companies (customers) currently using freight rail service.

The paper describes a novel approach to the demand responsive freight rail timetabling. The problem is modelled as a constraint satisfaction problem and solved using the relaxed constraint satisfaction approach. The variables are fixed and the consistency between X and Y variables are enforced adaptively for the number of iterations determined by the magnitude of a probability. The probabilistic learning algorithm based on a discrete choice model learns implicitly from the search history. Thus, it achieves the flexibility needed to solve freight rail timetabling models when the rail business strategy needs to be changed. With the proposed demand responsive freight rail timetabling model, we are able to find a profitable timetable whilst satisfying customer demand. The timetables lead to some reductions in total operating costs, enhance the level of customer service, and achieve the visibility to manage the customer satisfaction through demand responsive timetables. The results suggest significant benefits for both the rail carrier and its customers.

References:

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