The Train Driver Recovery Problem – Solution Method and Decision Support System Framework

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Every railway operator experiences disruptions during the daily operations. Danish railway operator DSB S-tog A/S is no exception. DSB S-tog A/S operates on an urban train network with at least 6 trains per hour in each direction departing from every station of the network and up to 30 trains per hour in each direction departing from the Copenhagen central station. Minor train delays on the network are recovered by re-establishing the original plan using the slack time built into the timetable or delaying other trains. Major disruptions in the train schedule are recovered by re-routing or cancelling trains. A train is re-routed if it is turned back before reaching the end terminal station or driven through some stations without stopping. A cancellation is applied either to a single train task or to a whole train line, resulting in cancellations of all train tasks of a particular line for a certain period of time.

Disruptions in the train timetable affect the train driver schedule. When a train is delayed, re-routed or cancelled, a driver might be late for the next scheduled train task of the duty. If the driver is not available in due time for a train departure, the train task is assigned to another driver. If there is no available driver to cover the train task, the train is delayed or cancelled, causing a propagation of disruptions in the schedule. At the present time the operational re-scheduling process of disrupted train driver duties is conducted manually. If the disruption is severe and many train driver duties are disturbed, this is a very complicated task to carry out.

The interest of the passenger railway operator DSB S-tog A/S in introducing automated decision support for the train driver dispatchers is a key motivation for this project. The project has been a part of a Ph.D.-study [4] at Operations Research section of the Department of Management Engineering at the Technical University of Denmark in 2006 – 2009, and is now handed over to the Analysis Group of the Planning Department at DSB S-tog A/S.

The train driver re-scheduling has received a very limited attention by Operations Research practitioners. An integer programming approach to a simultaneous train timetable and crew roster recovery problem, tested on the New Zealands Wellington Metro line, is presented in [8]. The crew re-scheduling problem for train driver duties disrupted due to the maintenance work on train tracks is solved by [2] for the largest passenger railway operator in The Netherlands, while [3] present an algorithm for operational re-scheduling of the train drivers on the Dutch railway network. The review paper [1] describes the topic of crew recovery within the airline industry.

We propose an optimization-based solution method for solving the *Train Driver Recovery Problem* (TDRP) and a prototype for the decision support system for the train driver dispatchers. The optimization framework is based on solving restricted TDRP instances with a rolling time horizon, aiming to modify the original duty schedule as little as possible. For a particular disruption we identify a *disruption neighbourhood*, which is a part of the driver schedule characterized by a set of train tasks and a set of train drivers. The initial disruption neighbourhood is identified by a set of drivers, who's duties contain train tasks which are known to be disrupted within a certain recovery period, a time period within which a recovery solution is aimed to be found. A train task is disrupted if it is delayed, cancelled, re-routed or uncovered, i.e. assigned to an absent driver. All train tasks belonging to the initial set of drivers within the recovery period are included into the initial disruption neighbourhood. The Train Driver Recovery Problem (TDRP) aims at finding a set of feasible train driver recovery duties for drivers within the disruption neighbourhood with minimum modification from the original train driver schedule, such that all train tasks within the recovery period are covered and the driver duties outside the recovery period and duties of drivers not included in the disruption neighbourhood are unchanged. If a feasible recovery solution is not found withing a certain disruption neighbourhood, the disruption neighbouhood is expanded by either adding more train drivers or expanding the recovery period of the problem.

The TDRP is formulated as a set partitioning problem, where variables represent recovery duties of train drivers. The set of generalized upper-bound train driver constraints ensure that each train driver is assigned to exactly one recovery duty in the schedule. The train task constraints have a set partitioning structure and ensure that each train task in the recovery schedule is covered exactly once. It is observed in [7] that the linear programming relaxation of the set partitioning formulation of the crew rostering problem, which has a similar structure to the TDRP, possesses strong integer properties due to the existence of the generalized upper-bound crew constraints, which contribute to the perfect structure of the submatrix, corresponding to each crew member.

The solution method for solving the Train Driver Recovery Problem is based on solving the TDRP-LP and finding an integer solution with a constraint branching strategy. Since the cost of the recovery is not determined by a physical cost of the driver schedule (the drivers are already paid to be at work), but rather by the fictitious cost which expresses how attractive each recovery duty is, the optimality of the solution is not as important as the feasibility of the solution. The TDRP-LP is solved with a column generation method based on a limited subsequence strategy, where recovery duties with negative reduced costs are generated by limiting the number of tasks (subsequences) a driver can perform after finishing any task in the duty. Starting with a small number of subsequences, it is gradually increased, allowing to consider less attractive subsequent tasks for recovery duties. When a feasible solution to the TDRP-LP is found, we consider the problem solved. If the initial number of drivers is not enough to cover all train tasks in the initial disruption neighbourhood, the disruption neighbourhood is expanded in two possible ways: either the number of drivers in the disruption neighbourhood is increased by adding available stand-by drivers or the recovery period is extended, including more train tasks from the involved drivers' duties. If the problem remains infeasible due to uncovered train tasks when there are no more available drivers to add to the disruption neighbourhood, the decision support system sends an infeasibility message to the dispatcher specifying which train tasks are uncovered and hence have to be delayed or cancelled.

If the solution to the TDRP-LP is fractional, a constraint branching strategy similar to the one described in [6] is applied in order to find an integer solution. Since every train driver submatrix in the set partitioning formulation of the problem is perfect, the fractions occur in the TDRP-LP only across train drivers' blocks of columns. It is therefore sensible on 1-branches of the Branch & Bound tree to force one driver r to cover a train task s, which also appears in another driver's optimal recovery duty while forbidding other drivers to include s in their recovery duties. On the 0-branch we forbid the driver r to cover the train task s. A depth-first search on 1-branches of the Branch & Bound tree is implemented and the branching procedure is terminated as soon as the first integer solution is found.

Real-life operational data is provided by DSB S-tog A/S in order to test the implemented solution method. Based on the computational experiments, we conclude that the proposed approach is indeed applicable for implementation in a decision support system for train driver dispatchers in practice. DSB S-tog A/S is working on using the research results obtained during this thesis and the programming code of the prototype to develop and implement the train driver decision support system in their operational environment.

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