A new railway timetable was introduced in the Netherlands on December 10, 2006. This timetable is cyclic and involves both passenger and freight trains. One hour of the new timetable between the cities Gouda and Utrecht is shown in Figure 1. In this paper we describe several combinatorial optimisation models that were developed for generating cyclic timetables. These models played an indispensable role in the planning process of the new Dutch timetable.

Cyclic Timetable

Schrijver and Steenbeek (CWI) developed a model for generating the basic structure of a cyclic timetable. Their model assumes that the infrastructure and the line system are given, as well as the connections for passengers or rolling stock that have to be realized between certain lines at certain stations. Moreover, for all processes in the timetable (like running between stations, and headways between trains), minimum and/or maximum process times are defined. The model then looks for appropriate departure and arrival times for all trains at the corresponding stations.

The problem of generating the basic structure of a cyclic railway timetable can be described as a Periodic Event Scheduling Problem. It can be represented by a directed constraint graph, where the nodes are the departure and arrival times and the arcs are the processes between the departure and arrival times.

The Periodic Event Scheduling Problem can be solved by applying constraint propagation techniques. These techniques are adequate if the railway infrastructure is utilized intensively, as is the situation in the Netherlands. In that case, having fixed certain well-chosen parts of the timetable, the remaining solution space for the rest of the timetable is small, resulting in relatively short computation times.

Routing Trains through Stations

In the first timetabling step, the stations are considered more or less as black boxes: the details of the routes of the trains through the stations are considered only in an aggregated way. Therefore, in a second step, it must be checked in detail whether, given the arrival and departure times that were generated in the first step, the trains can be routed through the stations and allocated to platforms.

The problem of routing a set of trains through a station can be solved by first listing for each train the feasible routes through the station. Next, each combination of a train and a feasible route can be represented by a node in a graph. Two nodes are connected by an edge if they belong to the same train, or if the corresponding combinations of trains and routes are conflicting. The routing problem thus reduces to the problem of finding a maximum weighted node packing in this graph.

This weighted node packing problem can be solved by applying the commercial mathematical programming opti-
mizer CPLEX, after several pre-processing techniques have been applied for reducing the size of the graph. Figure 2 shows part of the platform allocation chart for Gouda station in the new timetable.

**Robustness**
In the first timetabling steps, it is assumed that the process times in the timetable are deterministic. However, the real-time process times in the operations are stochastic. The robustness of the timetable against small disturbances can be improved by optimally allocating time supplements and buffer times in the timetable.

This optimisation can be supported by a stochastic optimisation model that considers the processes both outside and inside the stations. The model modifies an initially given cyclic timetable and, at the same time, evaluates the modifications by simulating the trains in the timetable under stochastic disturbances. The aim is to minimize the average delay of the trains. This model can be considered as a symbiosis of an optimisation model and a simulation model.

**Conclusions**
The models described here were used intensively in the development of the Dutch timetable for 2007. The same holds for the multi-commodity flow model that was developed for planning the corresponding rolling stock circulations and for the set-covering model that was developed for generating the crew schedules.

Altogether, mathematics played an indispensable role in the generation of the new timetable, the rolling stock circulation and the crew schedules. The mathematical models allowed several scenarios to be generated, and explicit trade-offs to be made between conflicting optimisation criteria. This leads to a higher overall quality of the plans, as well as to a reduction of the lead-time of the planning process.

Currently, we are investigating whether these models can also be applied to support real-time control processes. That is, how can plans be adapted in the case of a real-time disruption of the railway system such that the passenger service remains as good as possible? Here the time needed for computing appropriate solutions is more important than near-optimality of the solutions: heuristic methods will be required.

**Links:**
http://www.ecopt.nl
http://www.cwi.nl/pna1
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Railyard Shunting:
A Challenge for Combinatorial Optimisation

by Per Kreuger and Martin Aronsson

Efficient railyard shunting is essential to cargo transporters in rail networks. In this article we explore methods of handling the situation where the capacity of the shunting yard is insufficient to handle all outgoing trains.

Sweden’s largest rail cargo operator, Green Cargo, performs mainly three types of cargo transport: postal services consisting of fast point-to-point transports; system train services dedicated to large flows for particular customers; and wagon-load services. Railyard shunting occurs mainly for the third type.

In the wagon-load system, individual wagons are routed from point to point through a rail network generally consisting of five shunting yards of varying sizes throughout Sweden. Wagons are transported in trains that are assembled and disassembled at the shunting yards, each of which typically handles three or four incoming trains per hour. The flow of wagons through the network varies from day to day depending on demand.

**Railyard Shunting**
At the shunting yard, incoming trains are scheduled to arrive at fixed times but can use the entry group as a buffer and preparation area. Each incoming train is pushed over the barrier, where wagons are separated and roll down to the shunting group. Here switches are operated so as to distribute the wagons to a number of destination tracks. Figure 1 shows the layout of the medium-sized shunting yard.

There are several limited resources at the shunting yard:
- the entry group must be able to accommodate all incoming trains
- the barrier has a fixed capacity in terms of wagons per hour
- the shunting group limits the number of trains that can simultaneously be assembled.

Under ‘normal’ operation, a unique departing train is assembled at each destination track and departs at a predetermined time. In practice, this is not always feasible, since the capacity of the

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Figure 1: Schematic topography of a simple shunting yard.