The Netherlands Schedules Track Maintenance to Improve Track Workers’ Safety

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After several fatal accidents, improving the safety of rail-track workers became a political priority in The Netherlands. Maintaining the track was one of the most dangerous jobs in the country. ProRail divides its infrastructure into working zones to be taken out of service during maintenance. We developed a two-step method of constructing a four-week maintenance schedule in which each working zone of the main lines is closed to trains at night exactly once. The alterations in trains’ departure and arrival times are within the restrictions imposed by train operators. Workers have accepted the resulting schedule, which provides them with a manageable maximum workload per night. Such a schedule is unique in Europe. It has been in operation since 2000 and has clearly proven its benefits.

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is applied. Cheung et al. (1999) assumed that each day several hours were available for maintenance during which there were no trains, which is certainly not the case in The Netherlands.

The Safe Maintenance Project

In 2000, the Dutch railway network consisted of about 6,500 railway kilometers, more than 3,000 switches, and 400 yards. It handled about 5,000 trains per day. In 2000, it transported over a million passengers and 60,000 tons of freight per day. The network is operated mainly by the Dutch railways (http://www.ns.nl) and is fully financed and owned by the Dutch government.

In 1995 in Mook, a train hit and killed three track workers carrying out maintenance activities. This accident caused a national investigation, which showed that track workers had one of the most dangerous jobs in The Netherlands. Their individual risk (IR) was 3.4 deaths per 10,000 track workers per annum, three times higher than the IR in the building industry. The investigators concluded that to ensure safety, the railways should allow no trains on the parts of the rail infrastructure under maintenance. The track workers should be protected in space and time.

ProRail decided to combine maintenance activities as much as possible and to change corrective maintenance into preventive maintenance. In this way, it would minimize the number of times maintenance takes place and the total maintenance time, both of which would improve safety and reduce the inconvenience for train operators, passengers, and freight transport.

ProRail divided the complete Dutch railway network into working zones according to an unambiguous method based on track functionality (den Hertog et al. 2005). A working zone is the part of the railway network taken out of service when track workers are working on it. We call this practice protection in space.

After the working zones were in place, we developed a maintenance schedule for the working zones, which we call protection in time. This schedule was based on a new concept for carrying out maintenance. ProRail traditionally carried out maintenance where and when necessary (corrective maintenance). With enforcement of protection in time, carrying out corrective maintenance would cause an unacceptable disturbance for the trains. Under the new system, ProRail must combine all maintenance activities in a certain working zone and carry them out during one out-of-service period of about five and a half hours (net) every four weeks according to the maintenance schedule.

We started the project in January 1999 and developed a four-week cyclic maintenance schedule for the main lines, where most disturbances occur (Figure 1).

Passenger traffic on the main lines is greatest during the daytime. If the working zones of these lines were out of service in the daytime, then, for 90 percent of the zones, the disruption of railway traffic would exceed the restrictions on maximum delays for trains and on trains’ early departures and would even cause train cancellations. Therefore, ProRail cannot do maintenance in these zones in the daytime. At night,
however, passenger traffic is limited and the traffic consists mainly of freight trains. By grouping freight trains (one set of trains per hour in each direction), the railway can limit disruption. Therefore, ProRail performs maintenance in the zones at night.

ProRail will schedule maintenance of the remaining 10 percent of the main line zones, the peripheral railroads, and the yards in the daytime to balance the track workers’ workloads between day and night. We will focus on the construction of the nightly maintenance schedule for the main lines. The train operators (passenger and freight), ProRail Nieuwbouw (which lays and replaces tracks), and the track workers all impose restrictions on the maintenance schedule, some conflicting.

In the long run, train operators benefit from preventive maintenance because it reduces the risk of unforeseen disruptions from track malfunctions. However, planned preventive maintenance activities can also disrupt service. Maintenance work at night, in particular, slows freight traffic, except for Saturday night, when there is almost no freight traffic. Trains can be delayed, advanced, or even cancelled. We sought to minimize the inconvenience and to restrict delays and advances to some maximum time. For passenger trains, route changes are not permitted, but for freight trains, they are. Maintenance schedules should leave at least one of the (two or more) parallel tracks open. Train cancellations are acceptable only in extreme cases.

ProRail Nieuwbouw lays and replaces track, and their projects usually take several (consecutive) nights in one or more working zones. Because these projects are not considered as maintenance, they are not taken into account in the maintenance schedule. To carry out their projects efficiently, ProRail Nieuwbouw often wants additional zones free of traffic, potentially further disrupting railway traffic.

The track workers work for 10 contractors, each maintaining a designated part of the Dutch railway network. They must carry out the planned activities within the time slots in the maintenance schedule. Because the track workers’ capacity is limited at night and during the weekend, the contractors want to limit the work scheduled at night and in particular on the weekend. Moreover, the workload at night has to be balanced over the nights of the week as much as possible. The number of switches to maintain determines the workload.

Two-Step Solution Approach

We used a two-step solution method to draw up the maintenance schedule. In the first step, we specify single-track grids (STGs), which are sets of working zones that can be out of service simultaneously. In the second step, we assign the STGs to nights. One reason to assign STGs instead of working zones to nights is that train operators are used to the concept of STGs. The order in which Steps 1 and 2 are carried out can be sequential. However, reiteration between the steps is possible and can be necessary, for example, when the resulting workload per night is too high.

Step 1: Specifying Single-Track Grids

The main lines consist of more than 300 working zones. Assuming that we can find one time slot of five and a half hours per night, then 11 working zones on average will be out of service simultaneously per night in a four-week schedule. An STG is a set of zones that can be out of service simultaneously (Figures 2, 3, and 4). The resulting disruptions to railway traffic are within the restrictions imposed by the train operators. The corridor Kijfhoek–Venlo runs from Kijfhoek near the Rotterdam seaport to Venlo, which is near the border between The Netherlands and Germany (Figure 1). The arrows show the directions of the railway traffic when both tracks of the corridor are in service. A corridor consists of several sections. A section connects two major yards; section Tilburg–Boxtel, for example, connects the Tilburg and Boxtel yards.
operators, that is, maximums on delayed departures and early departures.

In principle, STGs should be based on working zones. However, the train operators traditionally based their work on sections (segments connecting two major yards within a corridor). Therefore, we define the STGs in terms of sections, which we later map onto the working zones. Hence, an STG defines a set of sections on a particular corridor (the railway infrastructure between two important yards). We cannot take both tracks in these sections out of service at the same time because that would totally block traffic (Figure 4).

We will summarize the definitions: A corridor is the railway infrastructure between two very big and important yards (Figure 2). A corridor consists of several sections. A section connects two major yards (Figure 3). Each section contains one or more working zones. A working zone is a part of a section (Figure 3). Such a working zone can be taken out of service for maintenance because signalling techniques protect such a working zone. An STG is a collection of sections for which we take either the left or the right track out of service (Figure 4).

Theoretically, a trade-off exists between workload balance and disturbance to the train traffic. However, ProRail decided that disturbance to the train traffic is the dominant criterion. So, the first goal is to find a schedule that minimizes disturbance to train traffic. Because ProRail performs maintenance at night when there are no passenger trains, it inconveniences only the freight trains. Train operators require “almost no disturbance,” meaning that freight trains should depart no more than a certain number of minutes earlier and arrive no more than a certain number of minutes later than the times in the original timetable.

The train operators carried out the first step with the help of a software system that supports the generation of the train timetables (Figure 5). They determined the STGs in the following way. They assumed that one track of a particular section, for example,
Breda–Gilze–Rijen (Figure 2), would be out of service during five and a half hours at night and they modified the train timetable to prevent trains from travelling on this track. Next, they searched for other sections for which they can take one track out of service without violating the restrictions on departure and arrival times. It is striking that when one track of a certain section is taken out of service, there are often other sections for which one track can be taken out of service with almost no added delays. All train operators evaluated the resulting deviations from the original, unhindered timetable. If the differences in departure times and arrival times violated the restrictions, then they adjusted the defined STGs.

We assumed that each zone was contained in one STG. Clearly, we could not schedule STGs on the same corridor for maintenance in the same night because the combined disturbances would violate the restrictions. Even STGs on different corridors sometimes cannot be combined, for example, when different corridors have sections in common. We assumed that the STGs were symmetric, which means that the timetable allows either the left or the right track to be out of service. We did this to avoid having to construct both left- and right-track timetables.

The data required for Step 1 are:
— the working zones within each section,
— the original, unadjusted timetables, and
— the train operators’ restrictions on departure and arrival times.

The results of Step 1 are:
— A timetable for each STG, specifying either the right or left track out of service at night for five and a half hours;
— A list of forbidden nights for each STG, which means that the STG may not be assigned to these forbidden nights;
— The working zones (left and right) for each STG, plus an extra STG containing zones not in the defined STGs; and
— Whether the STGs in each pair of STGs can be assigned to the same night or not.

The extra STG contains zones that are hard to maintain without too much nuisance. Maintenance of this extra STG is planned for a weekend night during which there is almost no train traffic.

We did not computerize the generation of STGs. Kingsale (2000) and Pelsers (2001) developed a model at the Centre for Quantitative Methods (CQM) that minimized the (maximum) delay for a predefined STG on a particular corridor. They also extended this model to deal with predefined STGs on two or more connected corridors. Stuurman (1996) developed a similar model. However, she assumed the STG to be a decision variable, that is to be defined by the model, while maximizing the number of single-track sections. All these models use an enormous amount of infrastructure data and hence require efficient interfaces with existing information systems. When we developed our maintenance schedule, we did not have time to develop such interfaces. However, when we have to create a new maintenance schedule, we can use these models to create efficient STGs.

Step 2: Assigning of Single-Track Grids to Nights

In Step 2, we assigned the STGs to nights. We took into account the allowed STG combinations (from Step 1) and the contractor’s workload per night. To avoid completely blocking corridors, we assigned the left and right tracks of an STG to different nights (Figure 6).

Implementing Step 2 manually is hardly possible. We developed a mixed-integer-programming model (Appendix) to carry it out and implemented the model as a software tool.

The data required for Step 2 are:
— The nights to which the STG may not be assigned,
— The zones contained in the left and the right tracks for each STG,
— The pairs of STGs that can be scheduled for the same night, and
— The workload and contractor for each zone.

An example of an STG with forbidden nights is the extra STG that should be planned for a weekend night.

The results of Step 2 are:
— The assignments of all STGs’ left and right tracks to nights,
— The nightly contractor workload, which depends on the number of switches and kilometers to be maintained according to the schedule, and
— A schedule for each night.

Results

Using our optimization tool, we can evaluate several maintenance schedules, examining the trade-off
between the number of nights in the schedule and the contractor’s workload (Figures 7a and 7b). The train operators evaluate the schedules for their effect on railway traffic. The contractors judge the distribution of their workload over the nights.

Depending on the scenario considered, the model’s objective and constraints can change, requiring changes in parameters (appendix). We modeled this mixed-integer-programming problem in AIMMS (1999) and used CPLEX 6.5 to solve it. For 16 nights, the model contained about 2,000 (integer) variables and 2,000 constraints. Solving one scenario took about 20 minutes on a Pentium 266 MHz, 64 MB computer.

We extended the model to evaluate different scenarios, for example, prioritizing nights by weighting the workload differently over the nights. We can also minimize the overall maximum workload instead of the sum of the individual maximum workloads (or

Figure 6: In Step 2, we assigned STGs to nights.

Figure 7a: In this example of workload distribution (number of switches) for a contractor in a four-week maintenance schedule with 16 utilized nights, the maximum workload is 13 switches in the nights from Sunday to Monday (third week) and from Sunday to Monday (fourth week). This example is based on artificial data because the real numbers are confidential.
we can minimize a combination of the two). We can maximize or minimize the number of nights (overall or per contractor) on which we schedule no activities. We can base the workload on the number of switches, on the number of kilometers, or on a combination. We can measure absolute workloads or relative workloads.

We compared the different scenarios with the help of diagrams showing the workload distribution of the contractors over the maintenance nights. The systems produce diagrams of the number of switches and of the number of kilometers to be maintained per night and per contractor (Figures 7a and 7b).

We distributed the chosen maintenance schedule widely among maintenance contractors, train operators, and ProRail Nieuwbouw personnel. With the lists of working zones scheduled to be out of service each night, we distributed maps showing the track sections planned for maintenance each night (Figure 8).

The first schedule agreed upon consisted of 16 nights for maintenance (out of 28). However, it turned out that the remaining 12 nights did not allow enough time for laying and replacing track. We had two options: to take some additional working zones out of service during the 16 maintenance nights for that work or to reduce the number of maintenance nights to 10. To avoid a lot of work developing timetables, we chose the second option. This left 18 nights for track building and renewal projects, which were sufficient, and we can “copy” the timetables for all maintenance nights every four weeks. After we optimized this scenario, the workload for the contractors was still acceptable. Moreover, the contractors had a schedule that was in line with the labor agreements: weeks 1 and 3, night work; and weeks 2 and 4, day work.

With the approval of all parties involved, we divided the 28 nights into three sets: six “red” nights to be used only for planned maintenance, 18 “green” nights to be used for work other than maintenance—laying and replacing track—and four “yellow” nights to be used for both kinds of work. In addition to the working zones scheduled for maintenance, additional zones may be out of service (within the restrictions imposed by the train operators) for other purposes.

**Concluding Remarks**

The maintenance project we worked on concerned several parties with different, sometimes conflicting, interests. With the help of OR techniques, we put the first maintenance schedule for railway infrastructure into operation in 1999. Nowhere in Europe had any infrastructure implemented such a concept.

The maintenance schedule for the main lines has proven its benefits. First, the new maintenance schedule made it possible for ProRail to implement the policy “werkloos is trein,” improving trackworkers’...
safety. Between 1999 and 2004, the individual risk dropped from 3.4 to 2.0 deaths per 10,000 track workers per annum. The fatalities since 1999 were not caused by accidents as in Mook because trains are no longer running on the tracks workers work on. Moreover, the maintenance schedule enabled a transition from corrective to preventive maintenance. The four-week, cyclic, preventive maintenance schedule has reduced the number of unplanned failures. Finally, the timetable developers’ workload decreased because the plan for the six (red) nights is fixed.

We expect that ProRail will soon put into operation a full schedule for the remaining working zones, the peripheral railroads, and the yards. Work on these zones takes place during the daytime as much as possible. We schedule zones that can be maintained only at night at the top of the main line schedule, filling the nights with low workloads first.
Passenger traffic is heavy during the daytime. Because the railway network is highly connected in The Netherlands, the smallest disturbance can cause enormous inconvenience. For the peripheral railroads and the yards, the parties involved must cooperate to specify which zones can be out of service and when.

The use of optimization models to generate STGs in the first step of the solution approach deserves further research. Kingsale (2000) and Pelsers (2001) have researched such an approach. Further studies should also consider section-based STGs.

### Appendix

**The Mixed-Integer-Programming Model**

We developed the mixed-integer-programming model to construct the maintenance schedule.

### Sets

- $C$ contractors.
- $S$ single-track grids (STGs).
- $T = \{\text{left, right}\}$ track sides.
- $N$ nights.

$P \subset S \times S$ set of permitted STG combination, i.e., $(s_1, s_2) \in P$, $s_1 \neq s_2$, when STGs $s_1$ and $s_2$ can be combined during one night.

### Parameters

- $\Lambda$ weight factor that indicates whether the workload is measured by the number of switches ($\Lambda = 1$) or by the number of kilometers ($\Lambda = 0$) or by a weighted combination of the two ($0 < \Lambda < 1$).
- $R_{sn}$ binary parameter that indicates whether STG $s$ can be assigned to night $n$ ($R_{sn} = 1$) or not ($R_{sn} = 0$), $s \in S$, $n \in N$.
- $Q_{stc}$ number of switches to be maintained on track side $t$ of STG $s$ by contractor $c$, $s \in S$, $t \in T$, $c \in C$.
- $V_{stc}$ number of kilometers to be maintained on track side $t$ of STG $s$ by contractor $c$, $s \in S$, $t \in T$, $c \in C$.
- $Q_{max}^c$ maximum number of switches that can be maintained per night by contractor $c$, $c \in C$.
- $M$ a big number.

### Variables

- $w_n$ binary variable that indicates whether night $n$ is used in the schedule ($w_n = 1$), $n \in N$, or not ($w_n = 0$).
- $x_{stn}$ binary variable that indicates whether track side $t$ of STG $s$ is assigned to night $n$ ($x_{stn} = 1$), $s \in S$, $t \in T$, $n \in N$, or not ($x_{stn} = 0$).
- $y_c$ maximum number of switches to be maintained per night by contractor $c$ over all nights, $c \in C$.
- $z_c$ maximum number of kilometers to be maintained per night by contractor $c$ over all nights, $c \in C$.

### Model

(P) Min $\sum_{c \in C} (\Lambda y_c + (1 - \Lambda)z_c) + M \sum_{n \in N} w_n$

s.t. $\sum_{n \in N} x_{stn} = 1 \quad \forall s \in S, t \in T$, (1)

$\sum_{t \in T} x_{stn} \leq R_{sn} \quad \forall s \in S, n \in N$, (2)

$\sum_{t \in T} x_{stn} + \sum_{t \in T} x_{stn} \leq 1 \quad \forall (s_1, s_2) \notin P, n \in N$, (3)

$\sum_{s \in S} x_{stn} \cdot Q_{stc} \leq y_c \quad \forall c \in C, n \in N$, (4)

$\sum_{s \in S} x_{stn} \cdot V_{stc} \leq z_c \quad \forall c \in C, n \in N$, (5)

$y_c \leq Q_{max}^c \quad \forall c \in C$, (6)

$\frac{1}{2|S|} \cdot \sum_{s \in S} x_{stn} \leq w_n \quad \forall n \in N$, (7)

$x_{stn} \in \{0, 1\} \quad \forall s \in S, t \in T, n \in N$, (8)

$w_n \in \{0, 1\} \quad \forall n \in N$. (9)

The objective function consists of two parts. First, we minimize the number of nights with planned maintenance in the schedule. After that, we minimize the sum of the maximum scheduled workload of the contractors. Constraints (1) and (2) ensure that the left and the right tracks of all STGs are assigned to exactly one allowed night. Moreover, they should be assigned to different nights. Constraints (3) ensure that only combinable STGs are scheduled in the same night. Constraints (4) and (5) determine the maximum number of switches and the maximum number of kilometers to be maintained per night by a particular contractor. The number of switches that one contractor can maintain simultaneously in one night is limited (constraints (6)). Constraints (7) determine
whether or not STGs are planned in a particular night in the schedule. When at least one of the STGs is assigned to night $n$, then the binary variable $w_n$ is forced to be one. Moreover, the left side of this equation is at most one, because we divide by the total number of STG-track sides. Finally, constraints (8) and (9) ensure that the decision variables for the assignment and the used nights are binary. There is no need to explicitly add the requirements that $y_e$ and $z_e$ have to be integer because these requirements are automatically fulfilled by the model.

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References


Drs. B. J. Klerk, chairman of the board, ProRail bedrijfsplanning, Postbus 2038, 3500 GA Utrecht, The Netherlands, writes: “This is a verification letter to let you know that the techniques and models described in the paper ‘The Netherlands Schedules Track Maintenance to Improve Track Workers’ Safety,’ written by J. I. van Zante–de Fokkert, D. den Hertog, F. J. van den Berg, and J. H. M. Verhoeven, were and are very valuable for our organisation. The resulting schedule has been operative in The Netherlands since 2000 and has proven to be very beneficial for our organisation.”