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Combined Optimization of Maintenance Works and Crews in Railway Networks

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Research Contribution

Our work contributes by developing optimal maintenance schedules for train lines, addressing the **integrated problem of maintenance works and crew scheduling on railway networks**. Our study has the additional features:

- We enhance a baseline maintenance work scheduling model with **crew scheduling**.
- We formulate a **binary nonlinear programming model** for maintenance works and crew scheduling and we reformulate it as a binary linear model to obtain an optimal solution.
- The integrated approach **reduces costs** by minimizing the maintenance duration through **task grouping**.

Assumptions

- the implementation considers an ideal railway network, with a low-frequency traffic load.
- the number of maintenance tasks and available crews is predefined.
- the length of each link is fixed.
- the planning horizon is 52 weeks, and one maintenance task corresponds to duration of one week.

Problem Formulation

$$\boldsymbol{Min} \sum_{l\epsilon L} \sum_{t\in T} C_{lt}\, M_{lt} + \sum_{k\epsilon K} \sum_{p\epsilon P} \sum_{l\epsilon L} B_{kpl} D_{kpl} \left(CCost_{kl} + MCost_{kpl}\right)$$

$$+ \sum_{e\in E} \sum_{t=1}^{T-1} \sum_{l\in LL} \sum_{q\in LL\nexists l} W_{lq} \left[1 - \left(\sum_{a\in A} H_{ealt} - \sum_{a\in A} H_{eal(t+1)}\right)\right] \qquad (1)$$

s.t.:

$$\sum_{t\epsilon T} Xalt = Gal \qquad \forall\, a \epsilon RA, l\epsilon L \qquad (2)$$

$$\sum_{t\in T} X_{plt} = \sum_{k\in K} I_{pl} D_{kpl} B_{kpl} \qquad \forall\, p \in PA, l\epsilon L \qquad (3)$$

$$X_{mlt} + X_{nlt} \le 1 \qquad \forall \in T, (m,n,l) \notin Comb \qquad (4)$$

$$\sum_{t=s}^{s+F_{al}} X_{alt} + \sum_{t=1}^{s+F_{al}-1} X_{alt} \le 1 \qquad \forall\, a \in RA, l \in L, s \in T \qquad (5)$$

$$\sum_{t=1}^{|T|-D_{kpl}+1} Y_{kplt} = B_{kpl} \qquad \forall\, p \in PA, l \in L, t \in \left(LST_{pl,}\, UST_{pl}\right) k \in K \qquad (6)$$

$$\sum_{s=t}^{t+D_{kpl}-1} X_{pls} \ge D_{kpl}\, Y_{kplt} \quad, \forall\, p \in PA, l \in L, t \in T, t \le T - D_{kpl} + 1, I_{pl} = 1, k \in K \qquad (7)$$

$$\sum_{k\in K} B_{kpl} = 1 \qquad \forall\, p \in PA, l \in L \qquad (8)$$

$$M_{lt} \ge X_{alt} \qquad \forall\, a \in A, l \in L, t \in T \qquad (9)$$

$$X_{alt} \in \{0,1\}, M_{lt} \in \{0,1\}, Y_{kplt} \in \{0,1\}, B_{kpl} \in \{0,1\} \quad \forall a \in A, t \in T, l \in L, k \in K \qquad (10)$$

Additional constraints of the enhanced model:

$$\sum_{a\in A} \sum_{l\in LL} H_{ealt} \le 1 \qquad \forall t \in T, e \in E \qquad (11)$$

$$X_{alt} = \sum_{e\in E} H_{ealt}\, Z_{ealt} \qquad \forall l \in L, t \in T, a \in A \qquad (12)$$

$$\left| \sum_{a\in A} H_{ea0t} - \sum_{a\in A} \sum_{l\in L} H_{ealt} \right| = 1 \qquad \forall t \in T, e \in E \qquad (13)$$

The objective function (1) **minimizes** the number of time periods for which major maintenance works are planned per planning horizon T. Namely:

- the **track possession cost**,
- the **cost of carrying out the scheduled projects**, and
- the **cost considering crew scheduling** to maintenance tasks.

With the additional constraints we ensure that :

- a crew can work only at one workstation, i.e., the execution of a maintenance task by a given work crew $e \in E$ at link $l \in LL$ can be performed by a single crew at a time $t \in T$.
- each scheduled maintenance task $a \in A$ must be equal to and correspond to a work crew $e \in E$ at each link $l \in L$, at each time $t \in T$.
- each work crew $e \in E$ at each time $t \in T$ is required to move either to a link $l \in L$ or stay in the depot.

Implementation

The implementation of the model aims to **test the enhanced model** and **evaluate its performance**. For this example, we have set:

- Link length: 10km, Number of links: 5
- 2 long-term/project works, and 3 short-term/routine works
- Number of work crews: 5
- Additional link for the depot
- Frequency and planning cycle for routine works
- Earliest and latest starting time, and duration for projects
- Route cancellation and inefficient resource usage costs per link

Results

The mixed-binary linear mathematical program was solved using the **Branch-and-Cut** algorithm of the GUROBI optimization software. The results include the annual maintenance schedules for tasks, work crew allocation to the planned tasks, and the total maintenance costs.

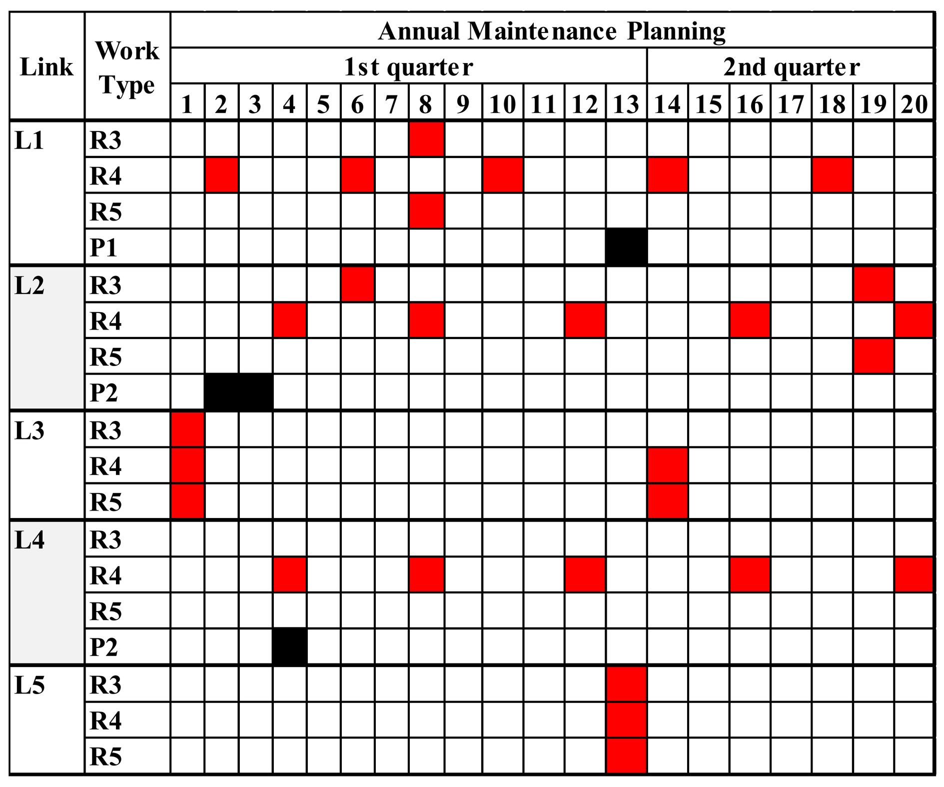

Figure 1. Annual maintenance planning results of the **baseline** model

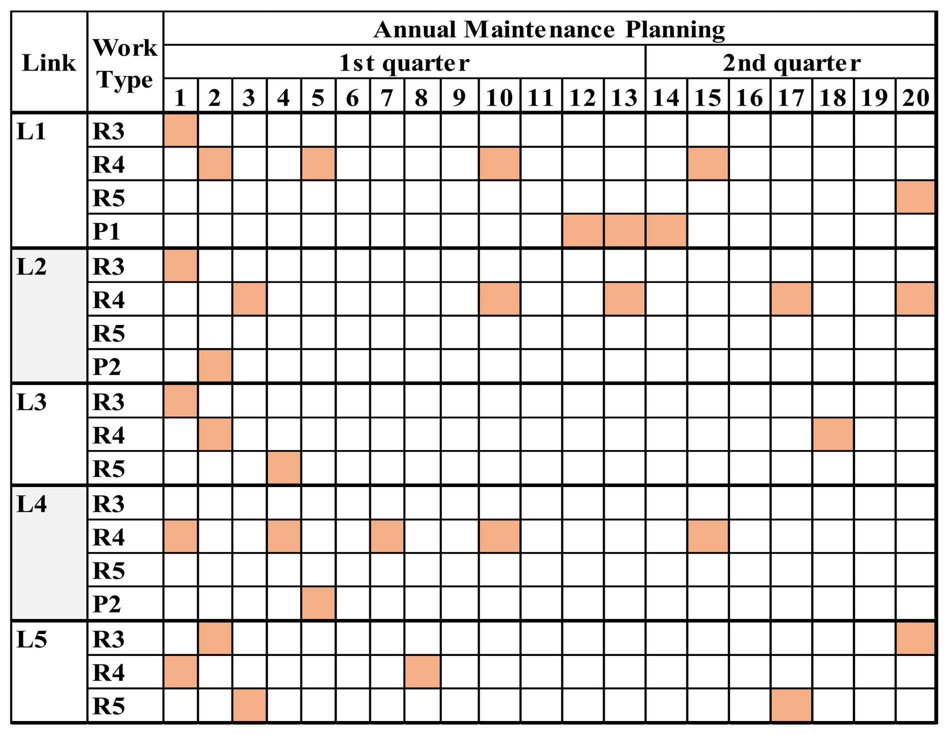

Figure 2. Annual maintenance planning results of the **enhanced** model

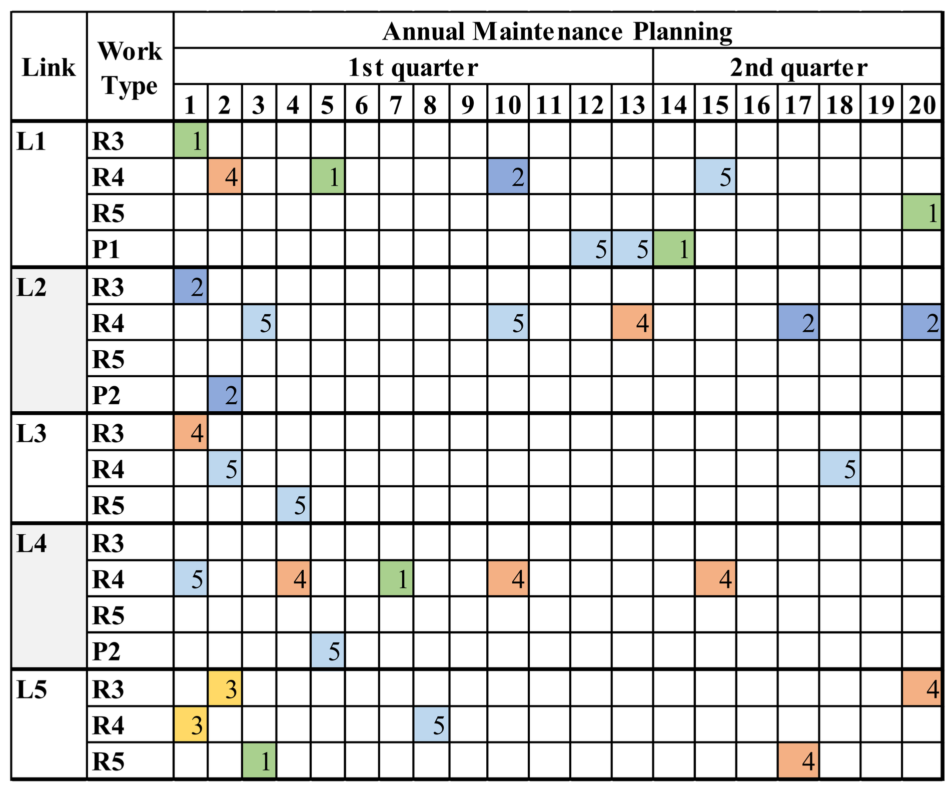

Figure 3. Scheduled maintenance tasks and crew allocation of the **enhanced** model

Key Findings

- grouping tasks on the same link significantly reduces costs, and the workload is efficiently distributed among the work crews.
- further research is required to examine computation time limits for optimal solutions, including adding tasks and exploring a larger network.
- it is essential to explore incorporating train timetables for precise task scheduling.
- testing scenarios with larger tasks would be beneficial for evaluating maintenance functionality and assessing cost distribution relative to operators' capabilities.

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