INTEGRATED SCHEDULING OF MAINTENANCE AND RENEWAL PROJECTS

Applications to railway and roadway infrastructures

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Infrastructure For The Future: Transport Research Finland
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INTRODUCTION
MAINTENANCE OF RAILWAYS AND ROADWAYS

The maintenance of equipment plays an important role in many industries, especially in transportation industry where a failure can be dangerous or disastrous.

- An effective preventive maintenance program of railways and roadways reduce the probability of costly corrective maintenance and avoid excessive maintenance.

Maintenance scheduling is a decision-making process of allocating resources over time to perform a collection of maintenance tasks.
PROBLEM DESCRIPTION
CONFLICT INTEREST OF STAKEHOLDERS

Asset manager carries responsibility for new construction, maintenance, renewal, capacity allocation, as well as traffic management.

The challenge for asset manager is how to collaborate with its stakeholders to meet their mutual goals on getting access to the available resources during infrastructure operation and maintenance.

- There is a great need for sophisticated tool to determine the optimal renewal time and schedule maintenance projects.
PROBLEM DESCRIPTION
RAILWAY AND ROADWAY AS A MULTI-UNIT SYSTEM

Infrastructure condition is not uniform in all locations and different locations has different maintenance requirements. Therefore, we divide each section of railway or roadway into units.

- Our aim is to find the sequence of maintenance actions with minimum cost and down time.
Optimization is the selection of a best element (with regard to some criteria) from set of available alternatives.

- The term optimize is “to make perfect”

**Input data**
- Maintenance history
- Maintenance costs
- Setup costs
- Maximum time interval between maintenance actions

**Optimization tool**

**Output results**
- Maintenance and renewal of each component in different locations (units) should be done in which time period.
SOLUTION APPROACH
MATHEMATICAL MODEL

In our developed tool, we used a mathematical procedure for determining the best value of decision variables in order to minimize the objective function while satisfying the constraints.

\[
\begin{align*}
\text{minimize} & \quad \sum_{t=1}^T p_t \times SC_t^A \\
& + \sum_{t=1}^T \sum_{l=1}^L \sum_{i=1}^I b_{it} \times SC_i^{P_l} + \sum_{t=1}^T \sum_{i=1}^I q_{it} \times SC_i^{P_l} + \sum_{t=1}^T q_i \times SC_i^{P_l} \\
& + \sum_{k=1}^K \sum_{l=1}^L \sum_{i=1}^I m_{ik} \times SC_i^{C_l} + \sum_{k=1}^K \sum_{l=2}^L w_{kl} \times (-SC_i^{C_l}) \\
& + \sum_{k=1}^K \sum_{l=2}^L \sum_{i=1}^I g_{it} \times SC_i^{C_l} + \sum_{t=1}^T \sum_{i=1}^I \sum_{k=1}^K w_{ik} \times (-SC_i^{C_l}) \\
\text{subject to} & \\
& \sum_{a=1}^{a} \left( m_{iak} r_{ik}^{h_{ab}} + r_{ia} \right) \geq 1 \quad \forall i, k \in K \\
& r_{ik} \leq \sum_{a=1}^{a} \left( m_{iak} + r_{ia} \right) \quad \forall i, k \in K, t \leq T - 1 - T_1 \\
& m_{iak} \leq \sum_{a=1}^{a} \left( m_{iak}^{h_{ab}} + r_{ka} \right) \quad \forall i, k \in K, u \leq T - 1 - T_1, t \leq u, 2 \leq h \leq H_i
\end{align*}
\]
OUTPUT RESULTS
HOW SOLUTIONS LOOK LIKE?

<table>
<thead>
<tr>
<th>Units</th>
<th>Planning horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>m_1</td>
</tr>
<tr>
<td>r_1</td>
<td>m_2</td>
</tr>
<tr>
<td>r_2</td>
<td></td>
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<td>...</td>
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</tr>
</tbody>
</table>

- r_1: renewal of component 1
- m_1: maintenance of component 1
- r_2: renewal of component 2
- m_2: maintenance of component 2

Maintenance history --- Planning horizon
Grouping:

- A technique to combine the executions of maintenance and replacement activities.
- Grouping allows savings on the preparatory works.

Balancing:

- A technique to find a balance between maintenance and renewal.
- Balancing allows to replace the component on its economic life rather than technical life.
BENEFITS OF GROUPING
EXAMPLE: 3 UNITS, 2 COMPONENTS, 3 TIME PERIODS

Comparing three scenarios for carrying out the replacement of component 1 in units 1-3 and maintenance of component 2 in units 1-2.

\[ r_1 : \text{renewal of component 1} \]
\[ m_2 : \text{maintenance of component 2} \]

<table>
<thead>
<tr>
<th>Units</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>r1</td>
</tr>
<tr>
<td>2</td>
<td>r1 m2</td>
</tr>
<tr>
<td>3</td>
<td>r1 m2</td>
</tr>
</tbody>
</table>

(a)

<table>
<thead>
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<th>Time periods</th>
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<tr>
<td>1</td>
<td>r1</td>
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<td>2</td>
<td>r1 m2</td>
</tr>
<tr>
<td>3</td>
<td>r1 m2</td>
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</table>

(b)

<table>
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<th>Units</th>
<th>Time periods</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>r1</td>
</tr>
<tr>
<td>2</td>
<td>r1 m2</td>
</tr>
<tr>
<td>3</td>
<td>r1 m2</td>
</tr>
</tbody>
</table>

(c)

**Down time cost:**
- (a) \(3 \times 100\)
- (b) \(2 \times 100\)
- (c) \(1 \times 100\)

**Preparation cost:**
- (a) \(2 \times 30 + 2 \times 20\)
- (b) \(1 \times 30 + 1 \times 20\)
- (c) \(1 \times 30 + 1 \times 20\)

**Installation cost:**
- (a) \(3 \times 5 + 2 \times 5\)
- (b) \(1 \times 5 + 1 \times 5\)
- (c) \(1 \times 5 + 1 \times 5\)

**Total setup cost:**
- (a) \(\Sigma = 425\)
- (b) \(\Sigma = 260\)
- (c) \(\Sigma = 160\)
BENEFITS OF BALANCING
EXAMPLE: 1 UNIT, 1 COMPONENT

- When an asset ages, maintenance is required increasingly often.
- The latest possible time for carrying out the next maintenance/renewal relevant to the previous maintenance is known (planning cycle).
BENEFITS OF BALANCING
EXAMPLE: 1 UNIT, 1 COMPONENT

- When an asset ages, maintenance is required increasingly often.
- The latest possible time for carrying out the next maintenance/renewal relevant to the previous maintenance is known (planning cycle).
BENEFITS OF GROUPING & BALANCING
EXAMPLE: 3 UNITS, 2 COMPONENTS, 16 TIME PERIODS

No optimization:
Total setup costs = 7440
M&R costs = 4800

32.2% setup reduction due to grouping and balancing

Integrated optimization:
Total setup costs = 4220
M&R costs = 4720
Multi-objective optimization of maintenance projects
Considering financial and operational concerns of various stakeholders.
- maximize potential traffic throughput,
- minimize disruption durations,
- maximize durations of breaks in between disruptions
- minimizing maximum yearly investment;
- minimizing delays in starting higher priority works
- minimize speed restriction and late night shifts

Managing the delivery of the maintenance projects collaboratively
- Analyzing the applicability of alliancing as a collaborative project delivery method between the key actors of maintenance project
• The developed optimization tool reduce the costs of maintenance without reducing the amount of maintenance by integrating grouping and balancing techniques.

• The tool can be used in capacity management, maintenance and renewal decision making process by considering conflict interests of stakeholders

  ▪ The tool can be used by both infra manager and contractors for different types of systems. They can Compare different maintenance and renewal scenarios.

Building good models is an art!

Essentially, good models are not those in papers but models that are in use.
REFERENCES

- Pargar, F. (2015). Preventive maintenance and renewal planning of infrastructures with application to a case study on railway tracks, 27th European conference on operational research (EURO), University of Strathclyde, Glasgow, Scotland.
Thank you!

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