Minimal Utilization Rates for Railway Maintenance Windows: A Cost-Benefit Approach

Society for Benefit-Cost Analysis: European Conference

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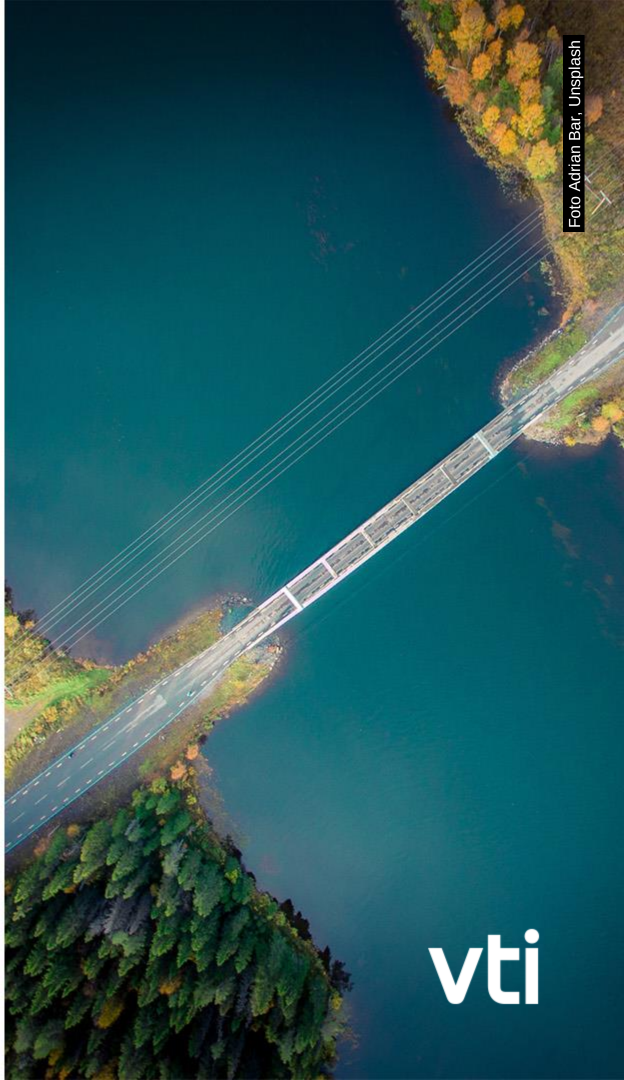
OUTLINE

1. Introduction
2. Method
3. Analysis & results
4. Conclusions

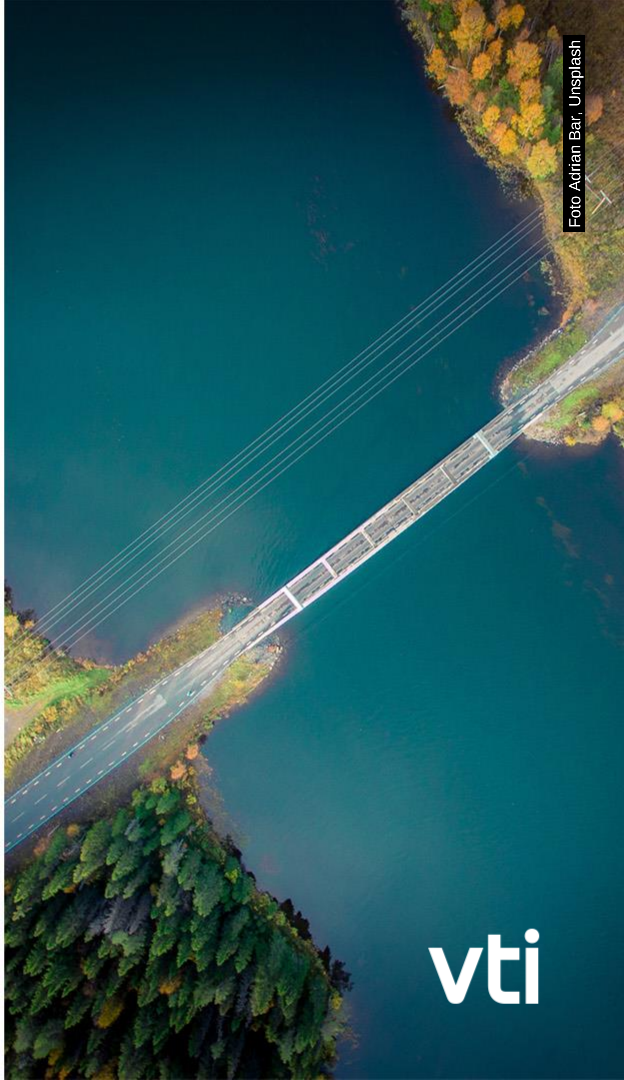


1. INTRODUCTION

a) Background

b) Research question

c) State-of-the-art



A) BACKGROUND

- **Rail infrastructures** require increasing investments due to, e.g., aging infrastructure (maintenance debt), larger and more complex networks, increased traffic.
- An example of such investments is **infrastructure maintenance** which has (in)direct **costs** (maintenance work, traffic loss) and **benefits** (increased future traffic reliability).
- To better perform maintenance activities, the concept of **maintenance windows (MWs)**, aka. maintenance access windows was recently introduced in Sweden.
  - MWs refer to **pre-allocated capacity** in the annual timetable guaranteeing **access to the tracks** for performing **recurrent maintenance activities**.

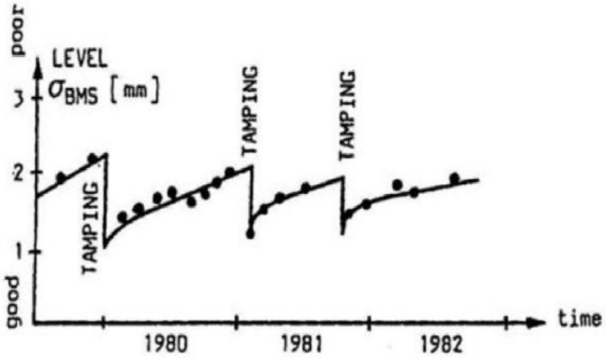
B) RESEARCH QUESTION

- Since its introduction in 2016, the **efficiency** of MW has been **questioned**.
  - Thus, the need to **improve their utilization rates**.
- The aim here is to study the (minimal) **utilization rates** of these windows.

- Given a specific/fixed **design of MWs**, we want to answer the following question:

*“ What is the **minimal utilization rate (MUR)** that would **justify** from a **socio-economic perspective** the pre-allocation of these MWs in the annual timetable? ”*

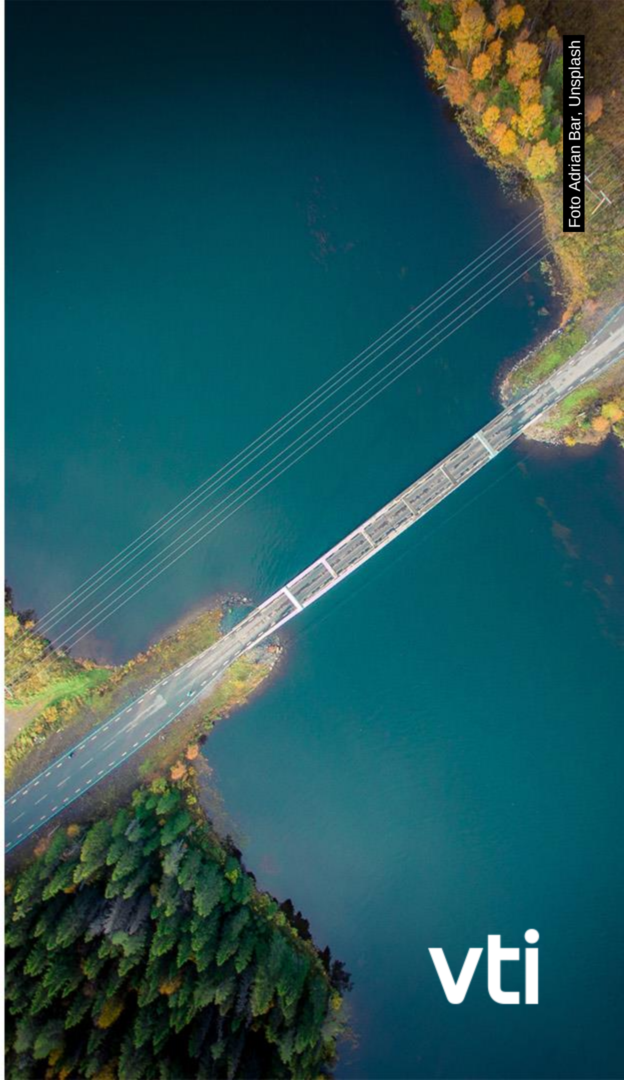
C) STATE-OF-THE-ART



- **Cost-benefit analysis (CBA)**
  - Maintenance costs are driven by, e.g., traffic volume, maintenance strategy, service quality, network density, etc.
  - Previous CBA models include work cost (material and labor), track access time, production/service losses and failure costs (cancellations, delays).
- **Life cycle cost (LCC)**
  - Costs throughout the life cycle of the asset(s), i.e., development, operation and phasing-out.
- **Reliability (RAMS)**
  - Reliability, Availability, Maintainability and Safety as indicators of the quality and performance of the infrastructure assets.

3. METHOD

a) Design of a MW
b) Utilization rate & total social cost
c) Work costs
d) Traffic losses
e) Reliability benefits



A) DESIGN OF A MW

- MWs are often **reserved** as **recurrent** slots for few hours per day over several weeks.
    - They can be scheduled during **day/night-times**
    - With **partial** (single-track) or **full closure** of the tracks
- Some design **examples**:
    - **MW-day**: 2 hours during day-time and weekdays, in total 2×5=10 hours/week.
    - **MW-night**: 5 hours during night-time and weekend days, in total 5×2=10 hours/week.

Given a MW design W, the total access time (in hours) is

$$T(W) = n_{weeks} \times n_{days} \times n_{hours}$$

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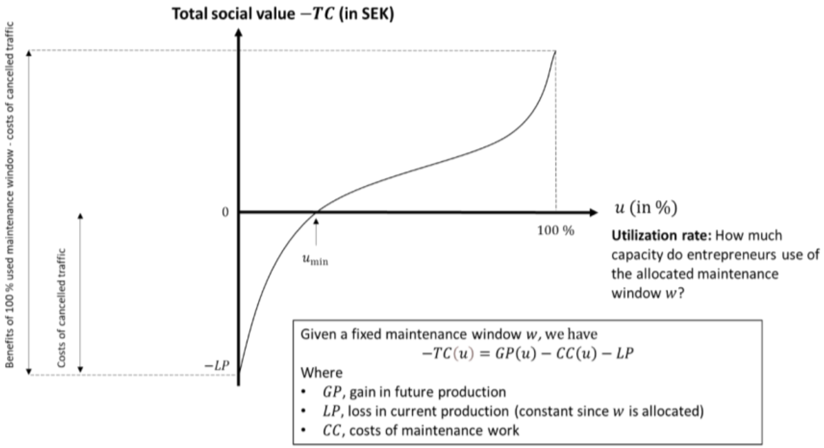
B) UTILIZATION RATE & TOTAL SOCIAL COST

- Given a MW design W, the **utilization rate** (in %) is defined as

$$u = \frac{T_{eff}}{T(W)} \ ,$$

where T_{eff} is the **effective** time spent on tracks.



- Alternative definitions exist, e.g.,
  - **Share of utilized slots.**
  - Share of canceled/performed activities.

- Given utilization rate u, the **total (net) social cost** (in SEK) can be defined as

$$TC(u) = CC(u) + LP - GP(u),$$

where CC is the work cost, LP is the traffic loss and GP is the gain in future traffic.

C) WORK COSTS

- Given utilization rate u, the **cost of work** $CC(u)$ can be formulated as

$$CC(u) = (1+\rho)\, k_{time} \left(t_{transport} + T_{eff}\right) + uK_{fixed}$$

- The **transport time** $t_{transport}$ depends on the number of shifts n_{shift} that are performed.
    - If **share of utilized access time** is used, such number can be calculated as

$$n_{shift} = \left\lceil \frac{T_{eff}}{n_{hours}} \right\rceil = \left\lceil u\, n_{weeks}\, n_{days} \right\rceil$$

K_{fixed} is the average fixed cost, e.g., for material

k_{time} is the work cost per time unit,

ρ is the compensation factor for night shifts

D) TRAFFIC COSTS

- Based on **Trafikverket's priority criteria**, the loss in traffic production (train **path cancellation**), due to the slots for maintenance windows W, is the following

$$LP = \sum_{\mathrm{k}} N_k(\mathrm{Time_k} \times (100\% + \mathrm{K_k}) \times (100\% + \mathrm{J_k}) \times \mathrm{B_k} + \mathrm{Distance_k} \times \mathrm{C_k}) \ ,$$

where $\mathrm{B_k}$ and $\mathrm{C_k}$ are, respectively, time and distance cost parameters for excluding a path of train type k. The percentage parameters $\mathrm{K_k}$ and $\mathrm{J_k}$ are used to account for the exclusion of train paths of type k.

- Assuming a frequency F (nb. dep./hour) on a single-track/direction, the number of cancelled trains is $N(W) = F \times T(W)$ in each direction.

- We study 3 categories, i.e., commuter (SP) and higher-speed (FX) and freight (GS).

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E) RELIABILITY BENEFITS

- The total gain in future traffic production is

$$GP(u) = u\,BR - (1-u)\,p\,CR$$

- The benefits from increased reliability BR is

$$BR = \int_0^{T_{asset}} \frac{Q(t) - Q_{\min}}{(1+r)^t}\,dt$$

  - The quality gain function $Q(t) = Q_0 \sqrt[i]{1 - \left(\frac{t}{T_{asset}}\right)^i}$ $\begin{cases} i = 1 \text{ (lin)} \\ i = 3 \text{ (exp)} \end{cases}$
  - The benefits just after maintenance

$$Q_0 = Q(t = 0^+) = C^{correction} + C^{delay}$$

with $C^{correction}$ as work cost but higher overhead $\rho^{corr} > \rho$ and T_{eff} is the average repair time, C^{delay} is calculated using ASEK values.

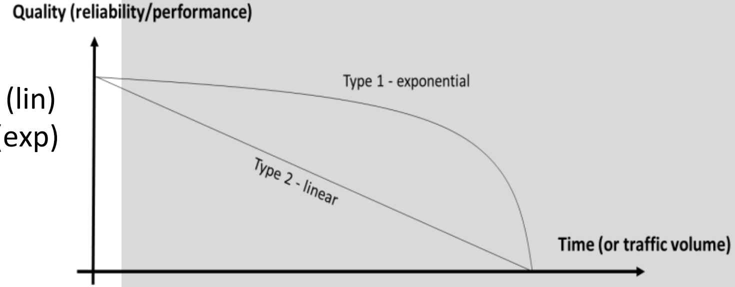
- The cost of failure risk CR is calculated as Q_0

BR is benefit from increased reliability

CR is the cost from risk of failure

p is the likelihood of a failure requiring immediate corrective maintenance

r is the discount factor

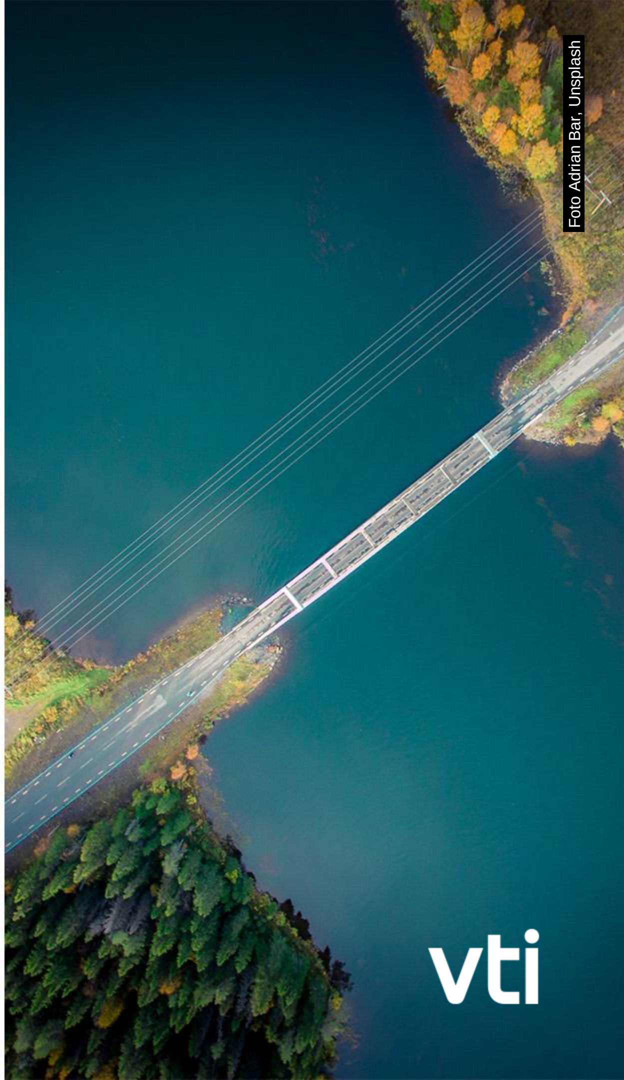


4. ANALYSIS AND RESULTS

a) Data (case study)

b) Analysis (test scenarios)

c) Results



A) DATA (CASE STUDY)

- Southern Main Line

	Commuter	Highspeed	Freight	Unit
Line	Norrköping - Mjölby	Stockholm - Malmö	Hallsberg – Malmö (vial Mjölby)	-
Distance (speed)	79 (140)	614 (200)	450 (135)	km (km/h)
Travel time	0:49	4:25	3:20	h:min
Passengers	66	138	-	pax/train
Goods	-	-	800	ton/train

- Data about cost parameters include
  - Maintenance cost parameters, e.g., transport time, labour cost per time unit, overhead for night shifts
  - Cost parameters for train cancellation per train category
  - Cost valuation of delays for passengers (commuter/long-distance) and freight trains

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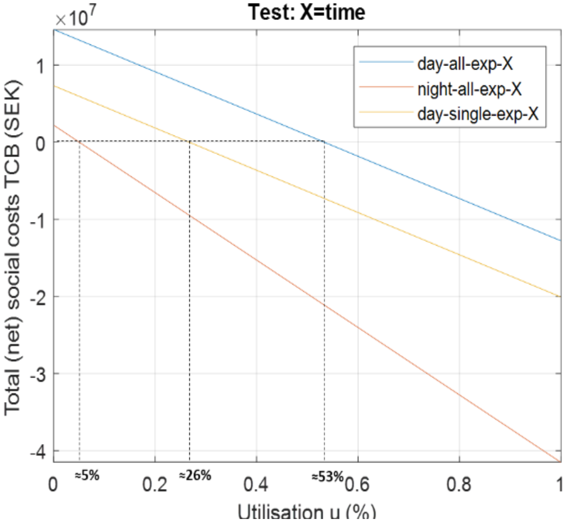
B) ANALYSIS (TEST SCENARIOS)

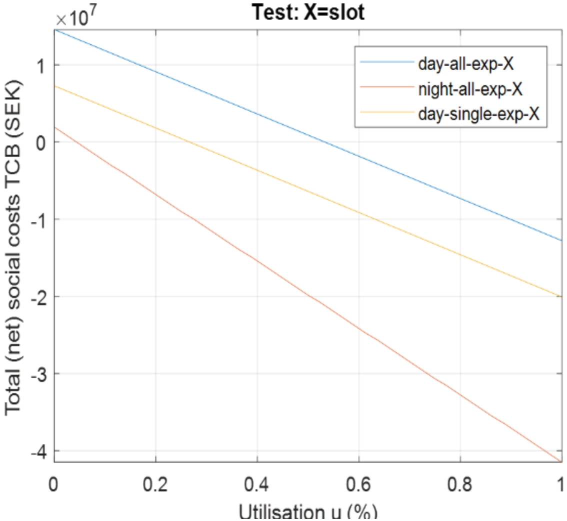
- **Three** main scenarios

Notation	Design of maintenance window (MW)	Potential traffic	Production loss	Work cost
day-all	MW-day & all track closure	mostly passenger	High	Low
night-all	MW-night & all track closure	mostly freight	Low	Medium
day-single	MW-day & single-track (speed reduction)	mostly passenger	Medium	High

- For each scenario
  - **Two** quality degradation functions, i.e., linear & exponential.
  - **Two** definitions of the utilization rate, i.e., access time & used slots.
- **Sensitivity analyses** of asset knowledge: minimal asset quality & degradation function

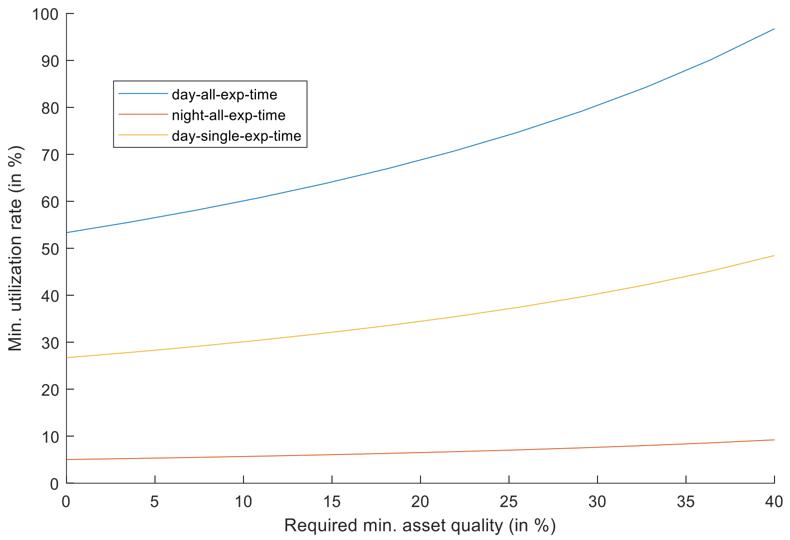
C) RESULTS (1/2)

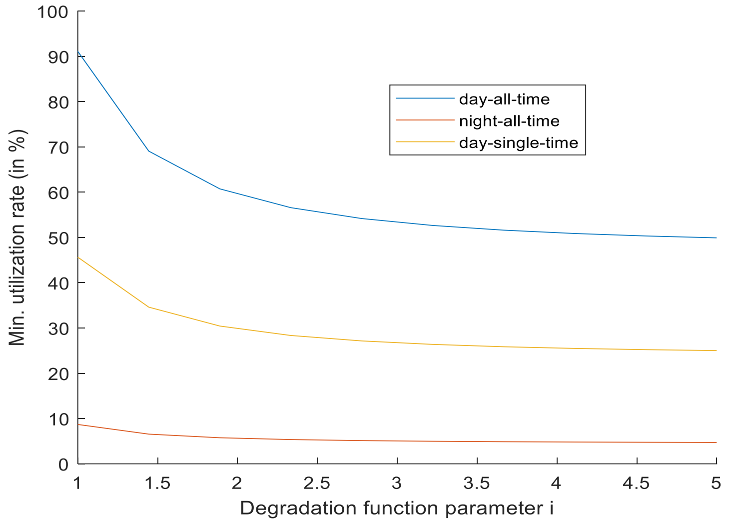




			Minimal utilization rate (in %)	
		Test scenario	**X=exp (i=3)**	**X=lin (i=1)**
Night	Full track (closure)	night-all-X-time	5	9
		night-all-X- slot	4	7
Day	Single track	day-single-X-time	26	45
		day-single-X-slot	26	46
	Full track (closure)	day-all-X-time	53	91
		day-all-X-slot	53	91

C) RESULTS (2/2) – SENSITIVITY ANALYSES

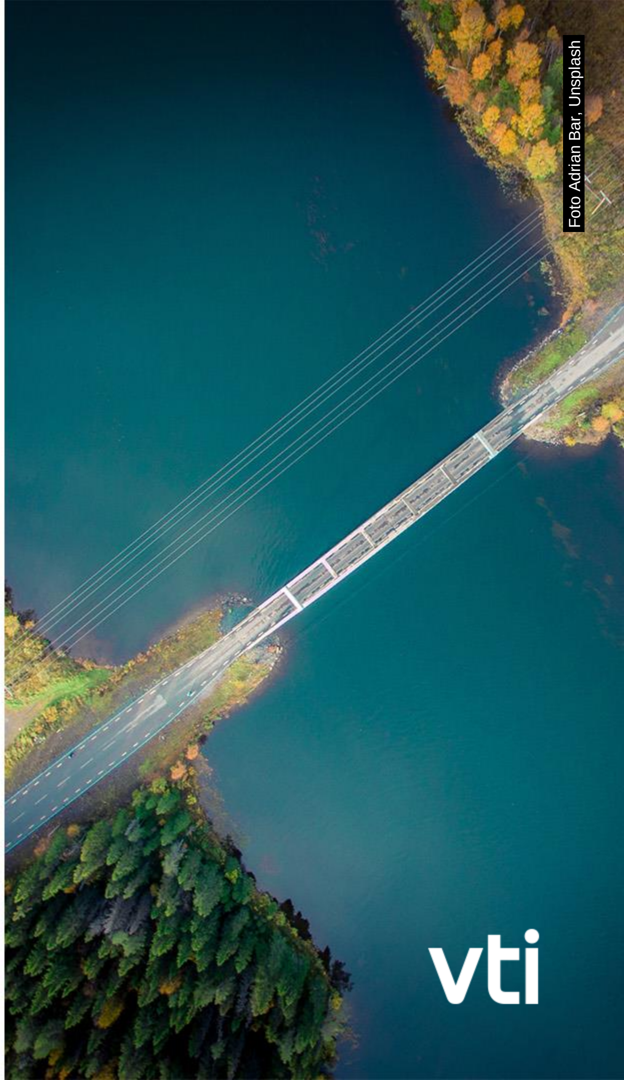




5. CONCLUSIONS

a) Discussions

b) Limitations & future works



A) DISCUSSIONS

- **Lower MURs** (5-50%) can be **accepted** during **night shifts or for partial closures.**
- **Higher MURs** (50-90%) are **required** for **full closures during day shifts**.

- Whether the rates are measured as share of **used window time** or share of **utilized windows** is **less importan**t, especially when higher MUR is required.

- Sensitivity analyses of **asset knowledge** show that parameters such as **asset degradation function** and **minimum asset quality** have **substantial effects** on MURs. **Traffic volumes** and **failure likelihood** have lesser effects.

B) LIMITATIONS & FUTURE WORKS

- **Unused** maintenance slots can be **potentially beneficial** for traffic production, e.g., increase robustness in case of disruptions. These benefits are **not accounted for**.
- The model does **not account for several other costs, benefits and externalities**, e.g., track access charges, environmental effects (emissions and noise) and the costs of associations or missing connections.
- Maintenance activities are **assumed to be ideally scheduled (perfect knowledge)**. However, these may be performed earlier/later than ideal.
- Based on the **limitations**, some improvement ideas for future work are:
    - Including **additional costs** (e.g., environmental) and **benefits** (e.g., robustness).
    - Modelling of **knowledge uncertainty**: maintenance activities performed **later** than ideal.
    - Modelling the relation between **degradation function** and **traffic volumes**.

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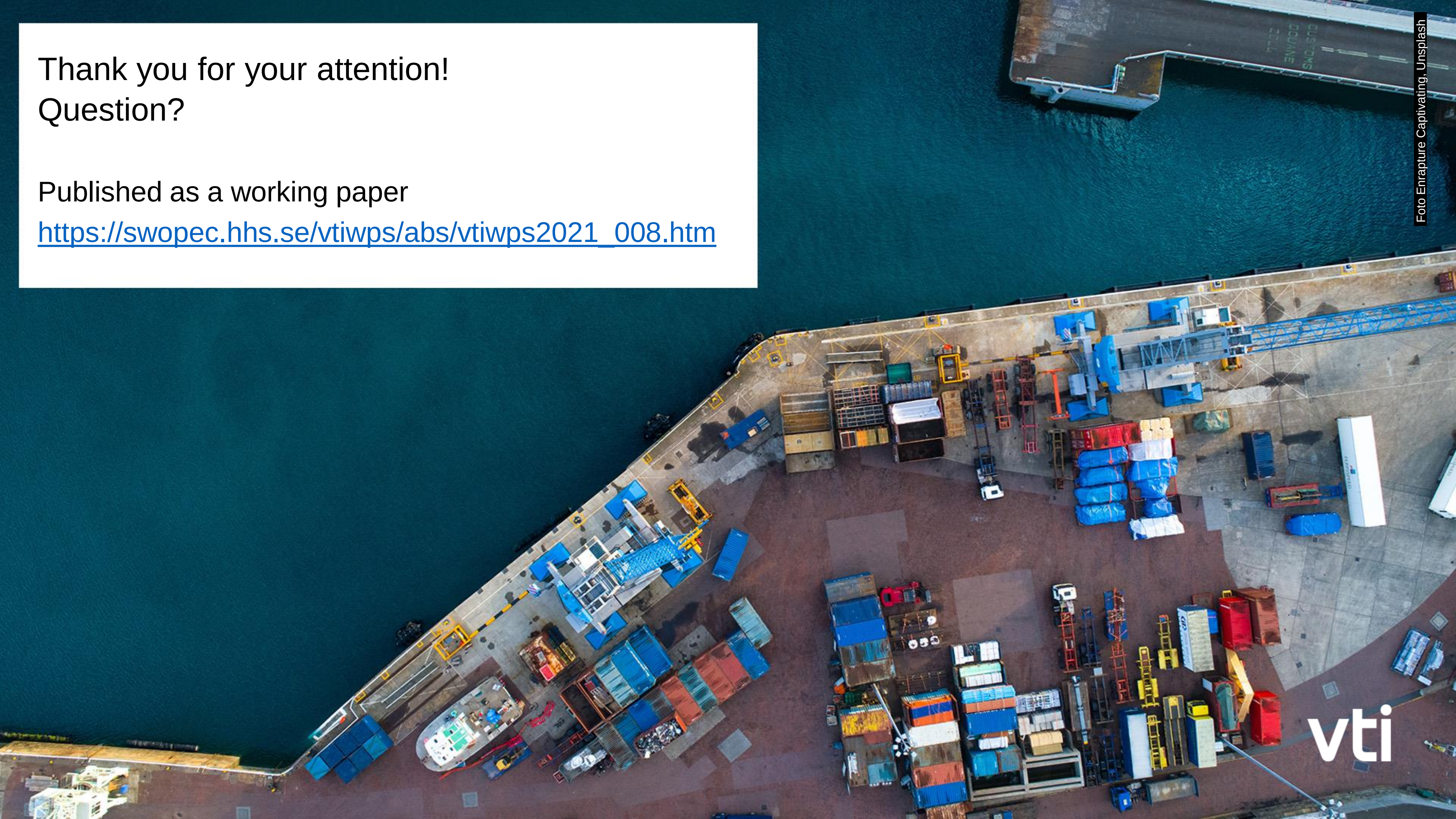
Thank you for your attention!
Question?

Published as a working paper

https://swopec.hhs.se/vtiwps/abs/vtiwps2021_008.htm



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