REVEALED PREFERENCE OF WAITING TIME AND CROWDING

Are commuter train timetables consistent with stated preferences of passengers?

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Outline

1. Introduction
2. Analytic model
3. Numerical study
4. Conclusions (and future works)

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1. Introduction

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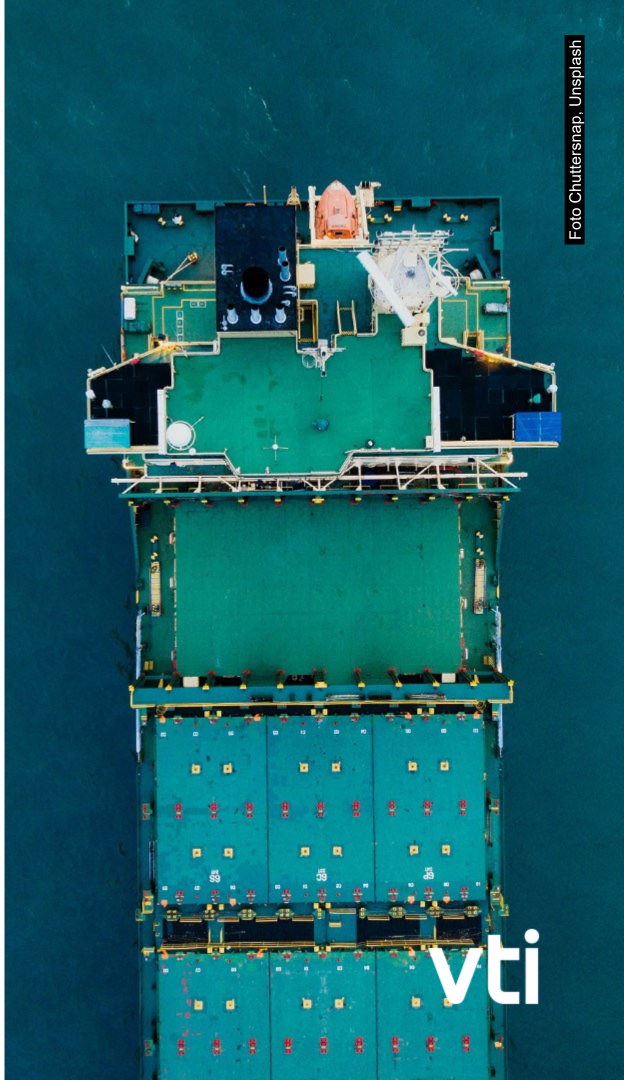
1.A. BACKGROUND

- Cost benefit analysis
  - Infrastructure investments (e.g., high-speed trains)
  - Operation planning (e.g., <u>commuter train timetabling</u>)

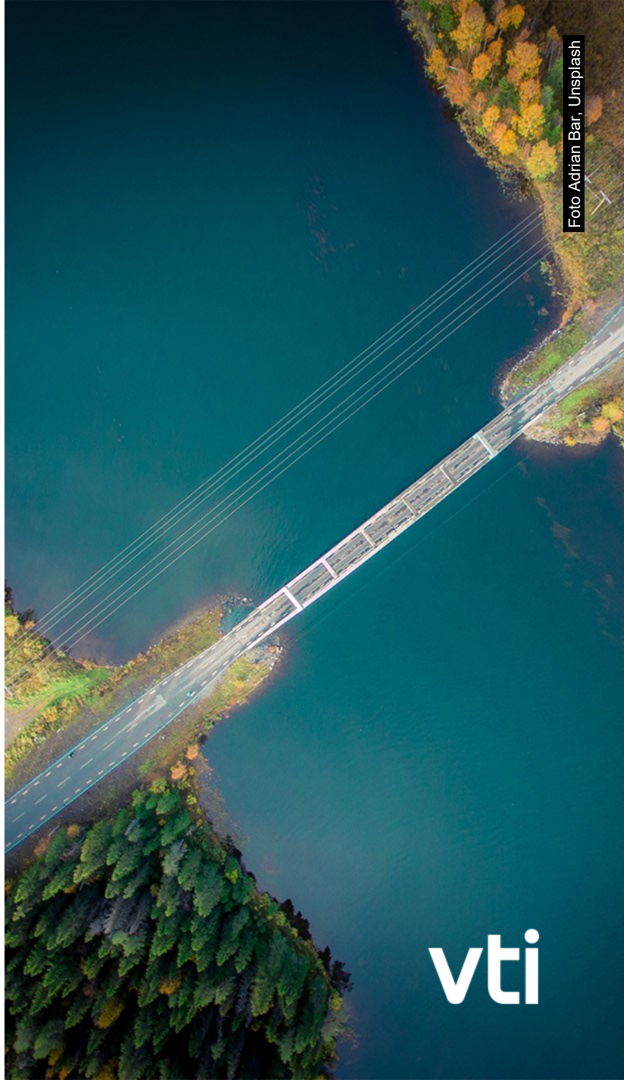
- Valuations perspectives
  - Consumer (individual/self-interested)
    - (Stated or revealed) preference of travellers
  - Organisation (citizen/social) preferences
    - <u>(Implicit) preference of PTAs</u> (e.g., SLL)



1.B. PROBLEM(S)

- Cost-benefit analysis for operation planning
  - *What is the societally optimal frequency of commuter train services?*
  - *Are commuter train timetables consistent with stated (consumer/passenger) preferences?*

- Revealed citizen preferences (e.g., waiting time and crowding)
  - *If not consistent, can this anomaly be explained?*
  - **Possible explanation:** *(by revealing) the implicit PTA's (vs stated passenger's) valuations.*



2. Analytic Model

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2.A. FORMULATION

N number of trains per hour, i.e., service frequency

Total societal costs

$$\mathrm{TC}(N) = \mathrm{PC}(N) + \mathrm{CC}(N)$$

$$\mathrm{TC}(N) = KN + \sum_{\substack{\text{station } i \\ \text{train } k}} \beta \frac{1}{2N} B_i^k + \sum_{\substack{\text{link } i \\ \text{train } k}} \alpha \left(1 + \gamma \left(\frac{F_i^k}{S} \right)^{\theta} \right) t_i \, F_i^k$$

Other parameters

- S train seat capacity
- B_i^k and A_i^k are number of passengers at station i boarding and alighting train k, respectively.
- F_i^k passengers in the link after station i onboard train k

$$F_i^k = \sum_{l \le i} \left(B_l^k - A_l^k \right); \;\; \forall i, k$$

Costs parameter	Notation
Production	K
Waiting time	β
In-vehicle crowding	γ and θ
Travel time	α

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2.B. OPTIMAL FREQUENCY

- Given valuation parameters (γ,β,θ), optimal frequency is

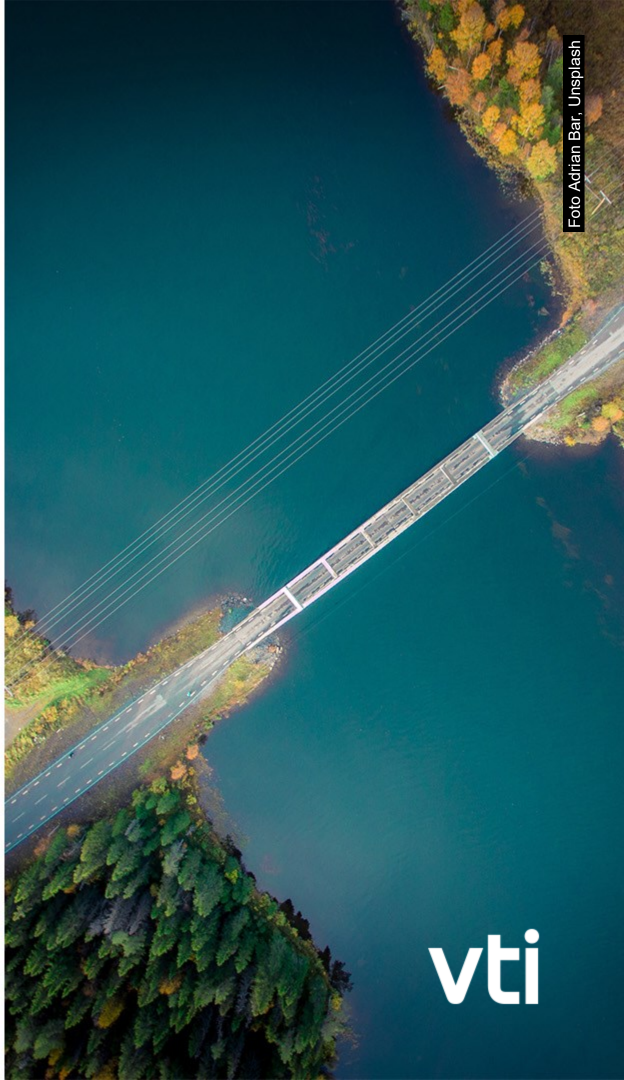
$$N^* = N^*(\gamma, \beta, \theta) = \underset{N \in \mathbb{N}^*}{\operatorname{argmin}} \operatorname{TC}(N)$$

- Example with $\theta = 0$ or $\gamma = 0$ (i.e., no crowding) - *square root principle* by Mohring (1972)

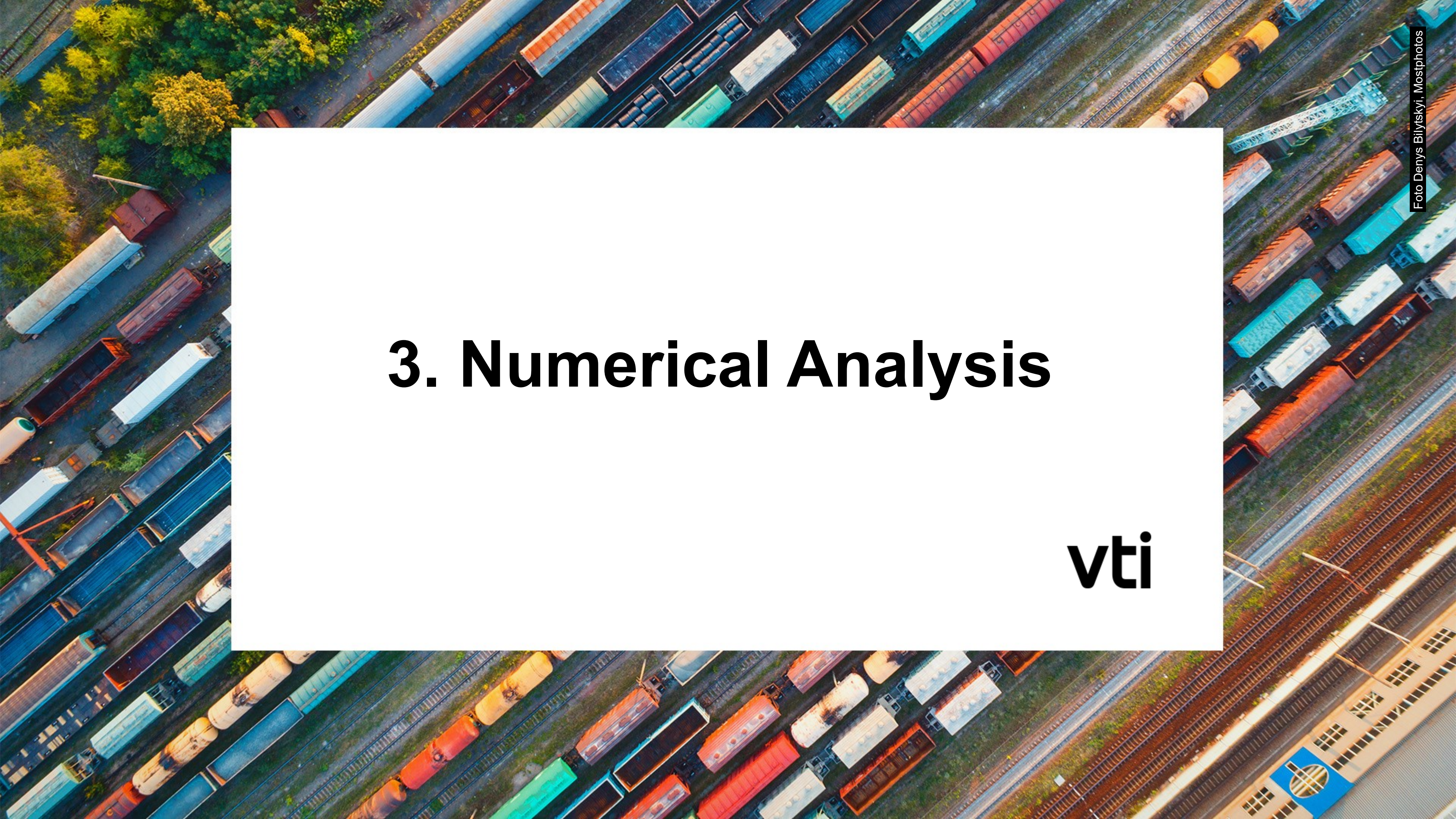
$$\frac{d\,\mathrm{TC}}{d\,N}(N^*) = K - \frac{\beta\mathcal{B}}{(N^*)^2} = 0 \Rightarrow \; N^* = \sqrt{\frac{\beta\mathcal{B}}{K_{PC}}}$$

where $\mathcal{B} := \sum_{i,k} B_{i,k}$

- General case ➔ No analytic formula!
  - E.g., integer values $\theta \geq 4$, in theory (Abel's impossibility theorem), no closed form exist (Abel, 1824)



3. Numerical Analysis



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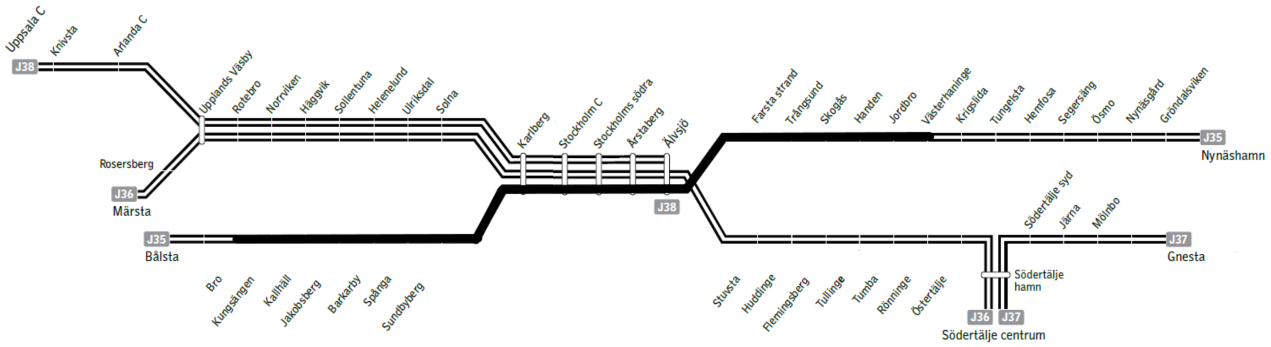
3.A. DATA (1/3)



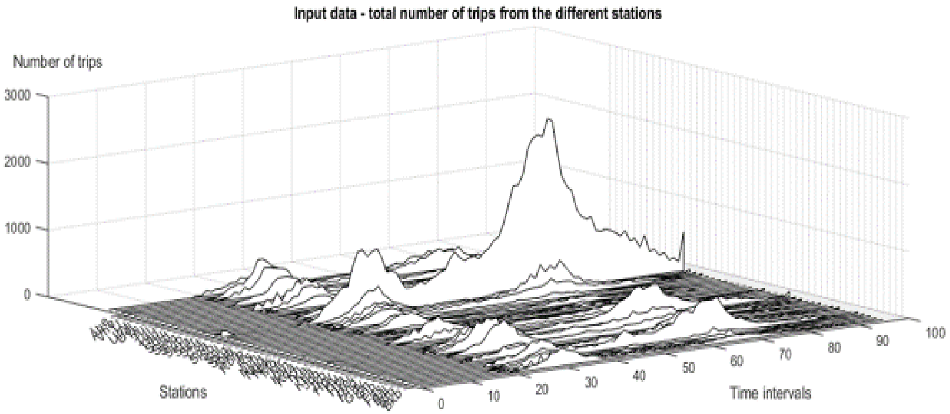
- Commuter train network
  - Stockholm, 2015 pendeltåg (i.e., pre-Citybanan)
  - Focus first on Kungsängen (Kän) → Västerhaninge (Vhe)

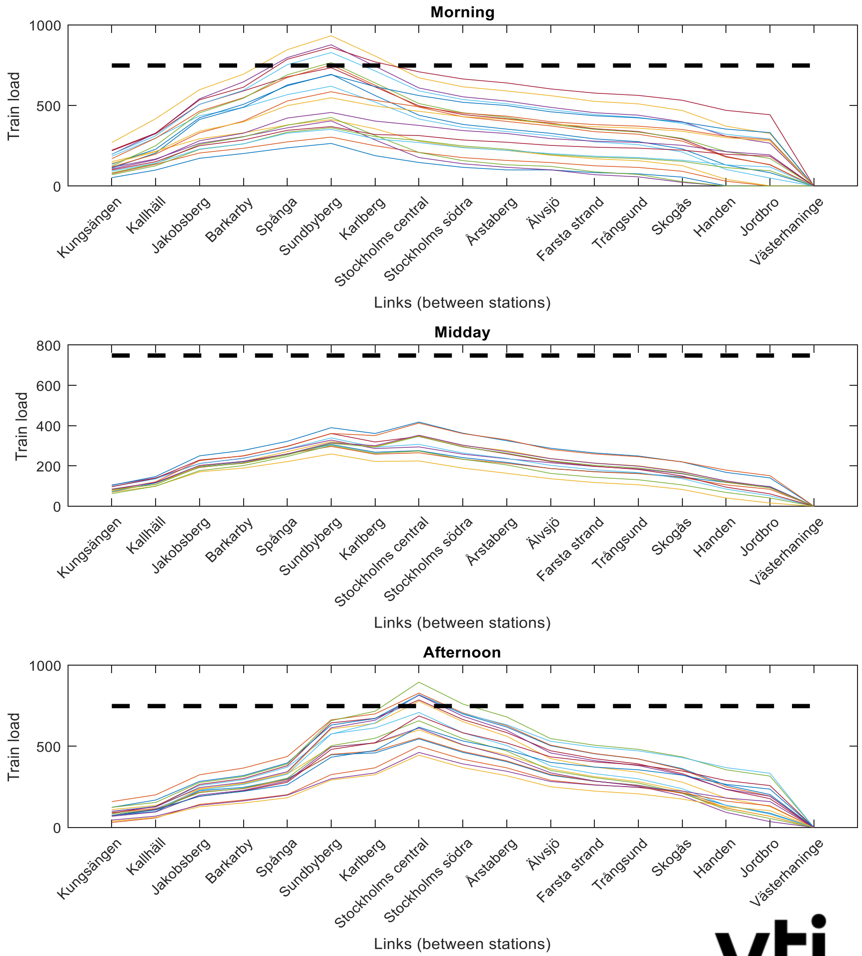
Time interval	Regular frequency [1]	Extra departures [2]	SL's total frequency N
Morning peak (6:00 - 9:00)	Every 15min	Every 20min	7.0
Mid-day off-peak (10:00 - 13:00)	Every 15min	-	4.0
Afternoon peak (15:00 - 18:00)	Every 15min	Every 30min	6.0

[1] Certain trains are running parts or beyond the studied line, e.g. to Älvsjö or Nynäshamn, from Jakobsberg.
[2] The provided frequency for extra departures is an average since not all operate with even intervals.

3.A. DATA (2/3)

- OD matrix and timetable (normal working day Sept 2015)
  - Passenger onboard each train
- Seating capacity





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3.A. DATA - COST PARAMETERS (3/3)

Parameter	Value	Reference
Travel time	$\alpha = 65.5 \text{ SEK per hour}$	Average 57 SEK/h (leisure) and 74 SEK/h (commutes), Eliasson and Borjesson (2014)
Waiting time	$\beta = 80$ SEK per hour	Assumption: average waiting time is less than 10 min (i.e. hourly train frequency higher than 3). Hence, average 86 SEK/h (leisure) and 74 SEK/h (commuting), Algers et al. (2010)
(in-vehicle) Crowding	$\gamma = 0.085$ $\theta = 3$	Curve fitting (i.e. parameter estimation), using results by Björklund and Swärdh (2017) of SP crowding valuation study in Stockholm (and two other Swedish large cities)
Operation	$K_{distance} = 30 \text{ SEK per wagon} - \text{km}$ $K_{time} = 2\,000 \text{ SEK per wagon} - \text{hour}$ $K_{fixed} = 3\,205 \text{ SEK per wagon} - \text{hour}$ $K_{overhead} = 9\ \%$	All parameter values for the producer costs are from (SLL, 2017). The reported fixed costs are $5.000.000$ SEK per year-wagon. Assumption: each wagon is operated 6 h per day and 260 days per year.

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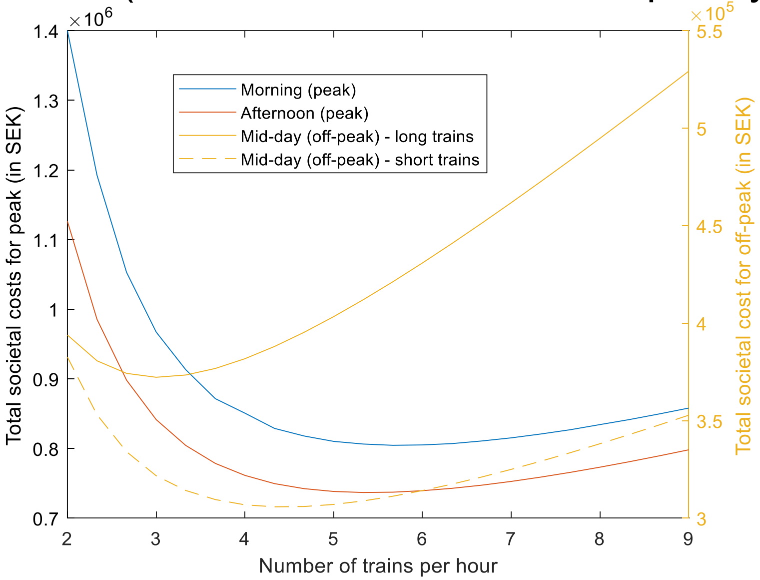
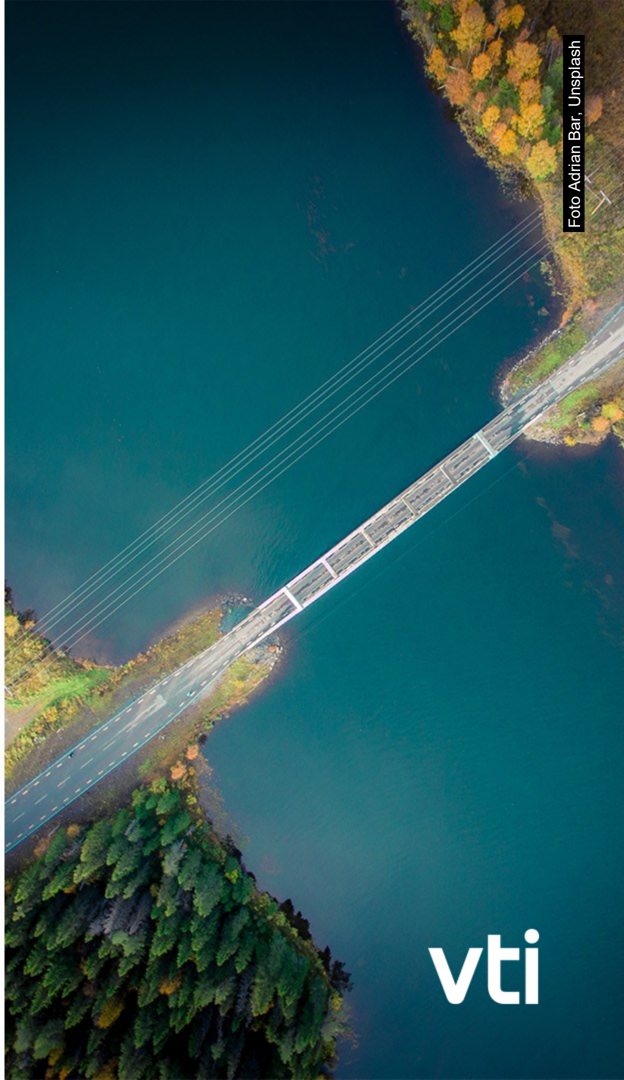
3.B. RESULTS (1/4)

- Societal costs (as a function of service frequency)



- Societally optimal frequency

Time interval	Optimal frequency (in trains/h)	SL's frequency (in trains/h)
Morning	5.7	7.0
Mid-day – long trains	3	4.0
Mid-day – short trains	4.3	-
Afternoon	5.3	6.0



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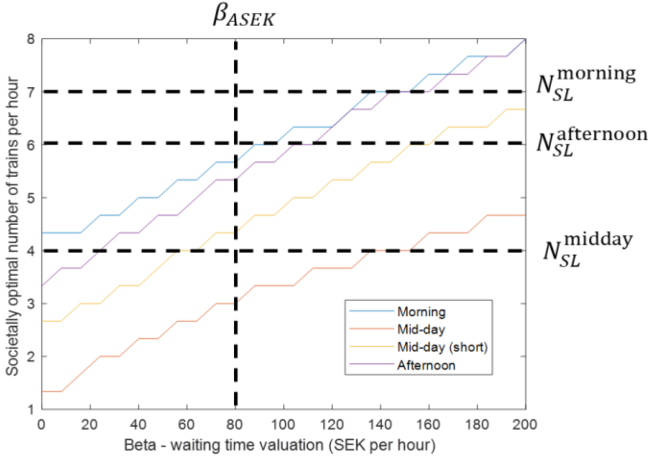
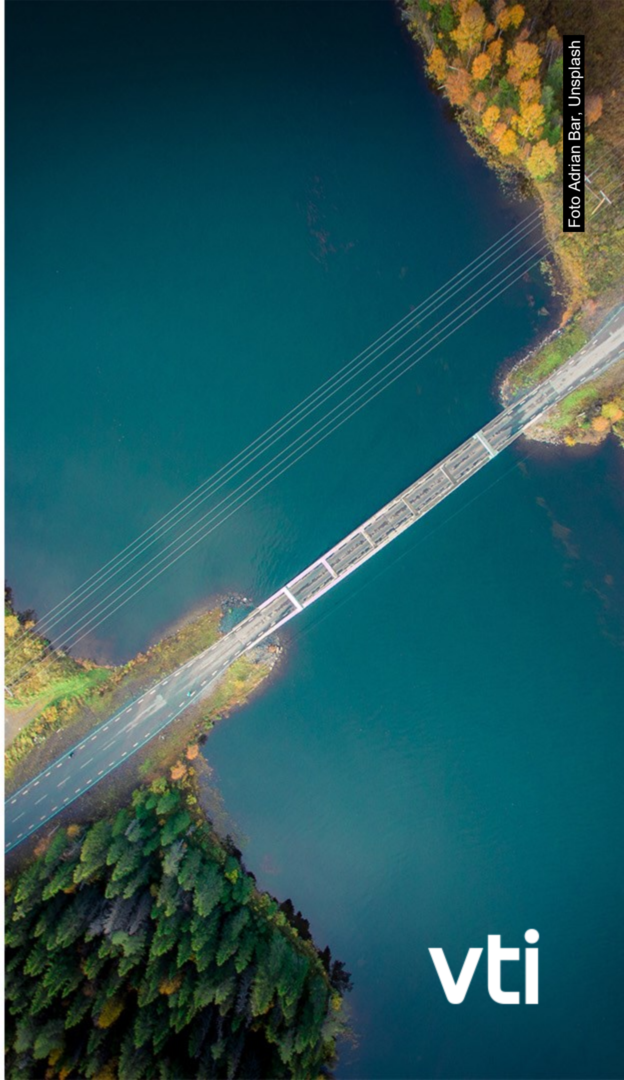
3.B. RESULTS (2/4)

- Waiting time



- Implicit values

Time interval	Revealed waiting time valuation ($\beta_{ASEK} = 80$ SEK/h)
Morning	144
Mid-day	144
Mid-day (short)	(60)
Afternoon	156



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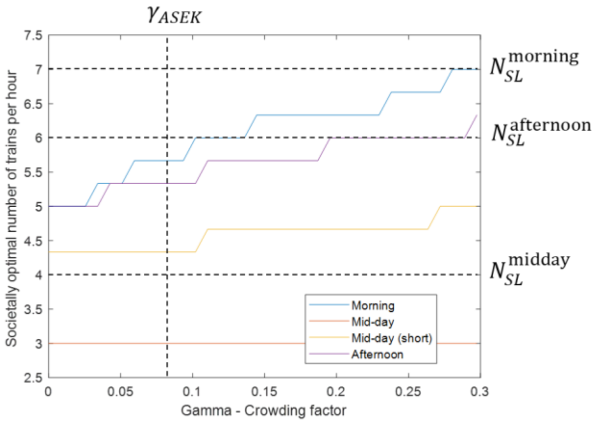
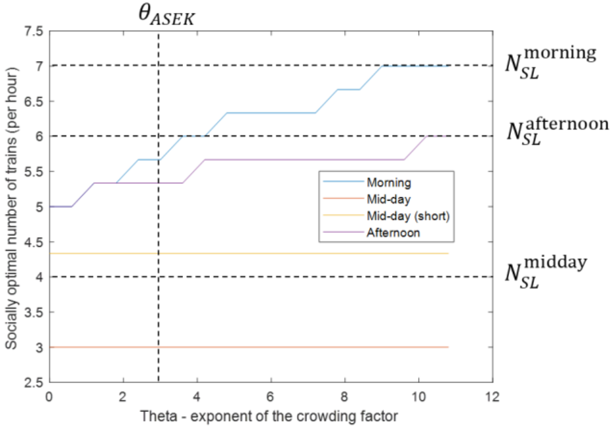
3.B. RESULTS (3/4)

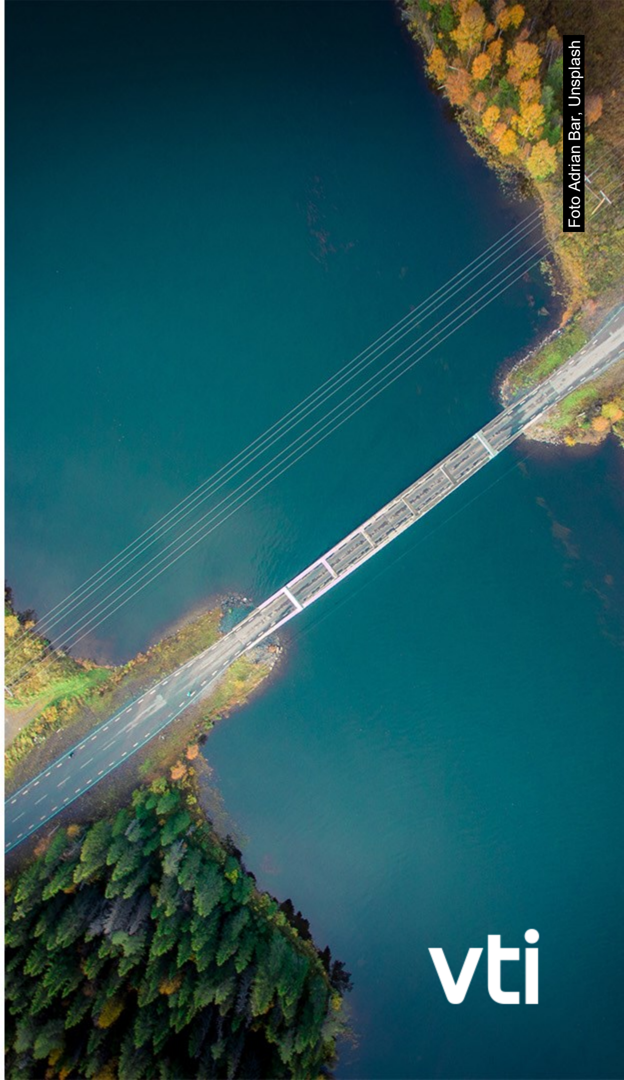
- Crowding (in-vehicle)





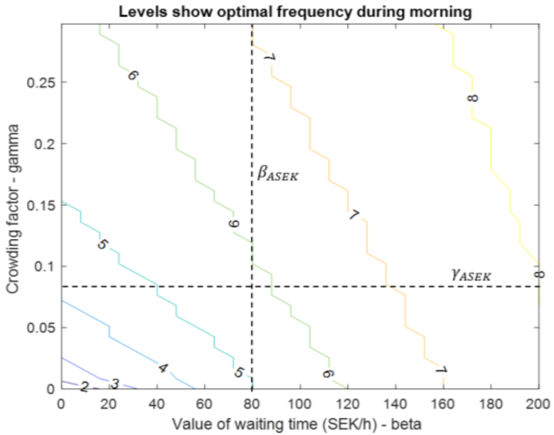
- Implicit values

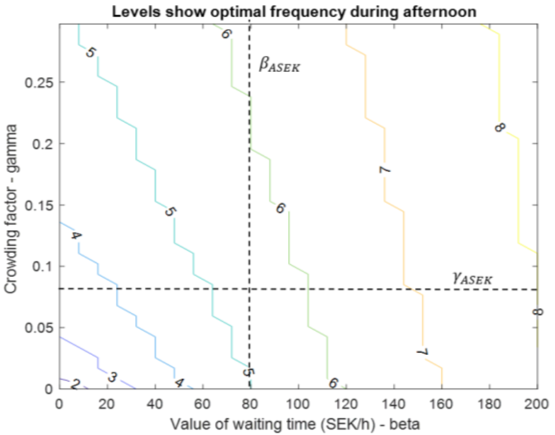
Time interval	Revealed crowding factor ($\gamma_{ASEK} = 0.085$)	Revealed crowding exponent ($\theta_{ASEK} = 3$)
Morning	0.281	9
Afternoon	0.196	10



3.B. RESULTS (4/4)

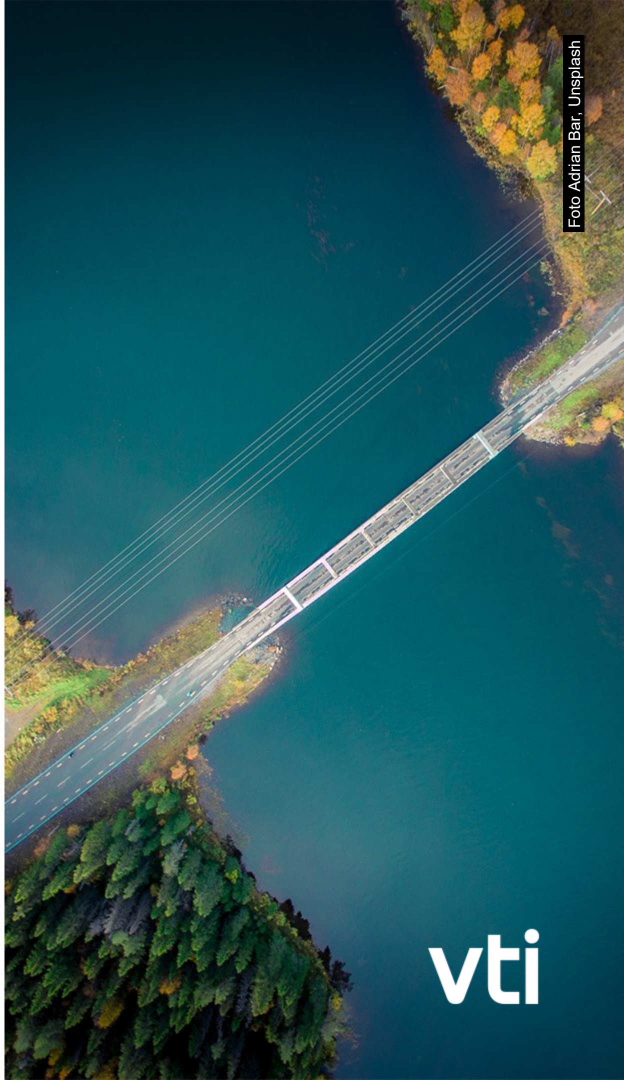
- Joint analysis (waiting time and crowding)





- Other lines and directions (optimal frequency)

	SL	Kän → Vhe (Southwards)	Vhe → Kän (Northwards)	Upv → Tu (Southwards)	Tu → Upv (Northwards)
Morning	7.0	5.7	5.7	6.7	7.3
Mid-day (long)	4.0	3.0	3.3	3.3	3.3
Mid-day (short)	-	4.3	5.0	5.3	5.3
Afternoon	6.0	5.3	5.7	6.7	6.3



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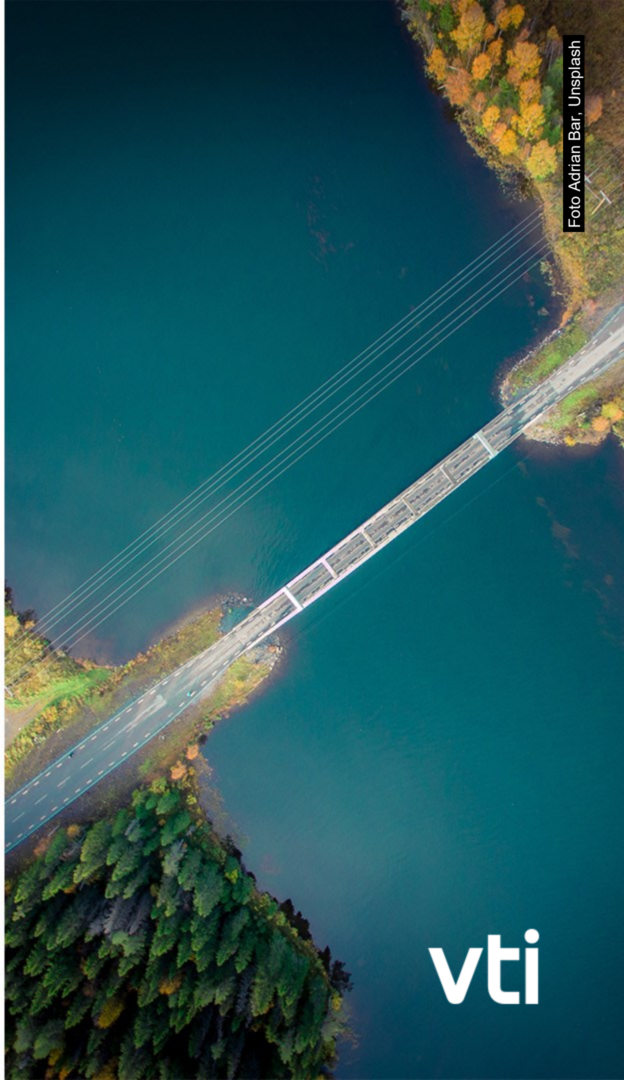
4. Conclusions (and future works)

4.A. CONCLUSIONS

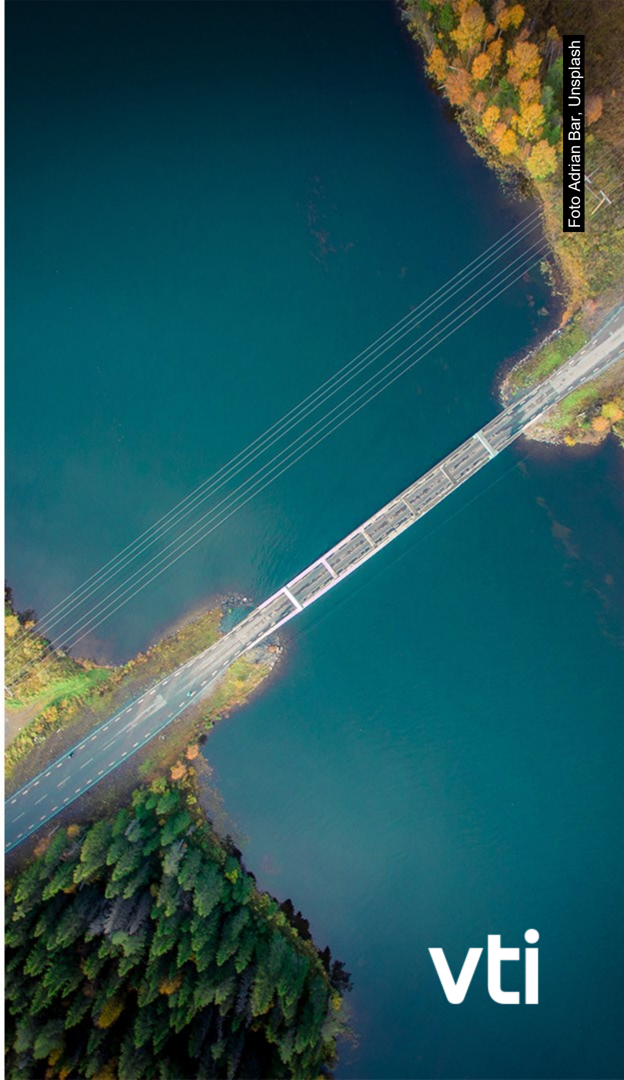
- We showed the use of CBA for operation planning
- Studied the societally optimal service frequency
  - Generally, slightly lower than PTA’s choices
  - Other factors, e.g., infrastructure constraints and punctuality.
- Revealed (implicit) PTA’s valuation of waiting time and crowding
  - Can be explained mainly by PTA’s higher (implicit) valuation of waiting time
  - Crowding valuation has no (off-peak) to negligible (peak) effect compared to waiting time.



4.B. FUTURE WORKS

- Optimisation of commuter traffic (<u>planned work</u>)
  - Cost benefit analysis (this study) + timetable optimisation
  - Different types of timetables (period, skip-stop)

- Other ideas
  - Different (or combination of) modes, e.g., bus, metro.
  - Also consider e.g.,
    - Delays, interchanges and capacity restrictions (infrastructure problems, maintenance possessions)
    - Trip distribution (OD) over multiple days (average, variance)



Thank you for you attention!
Question?

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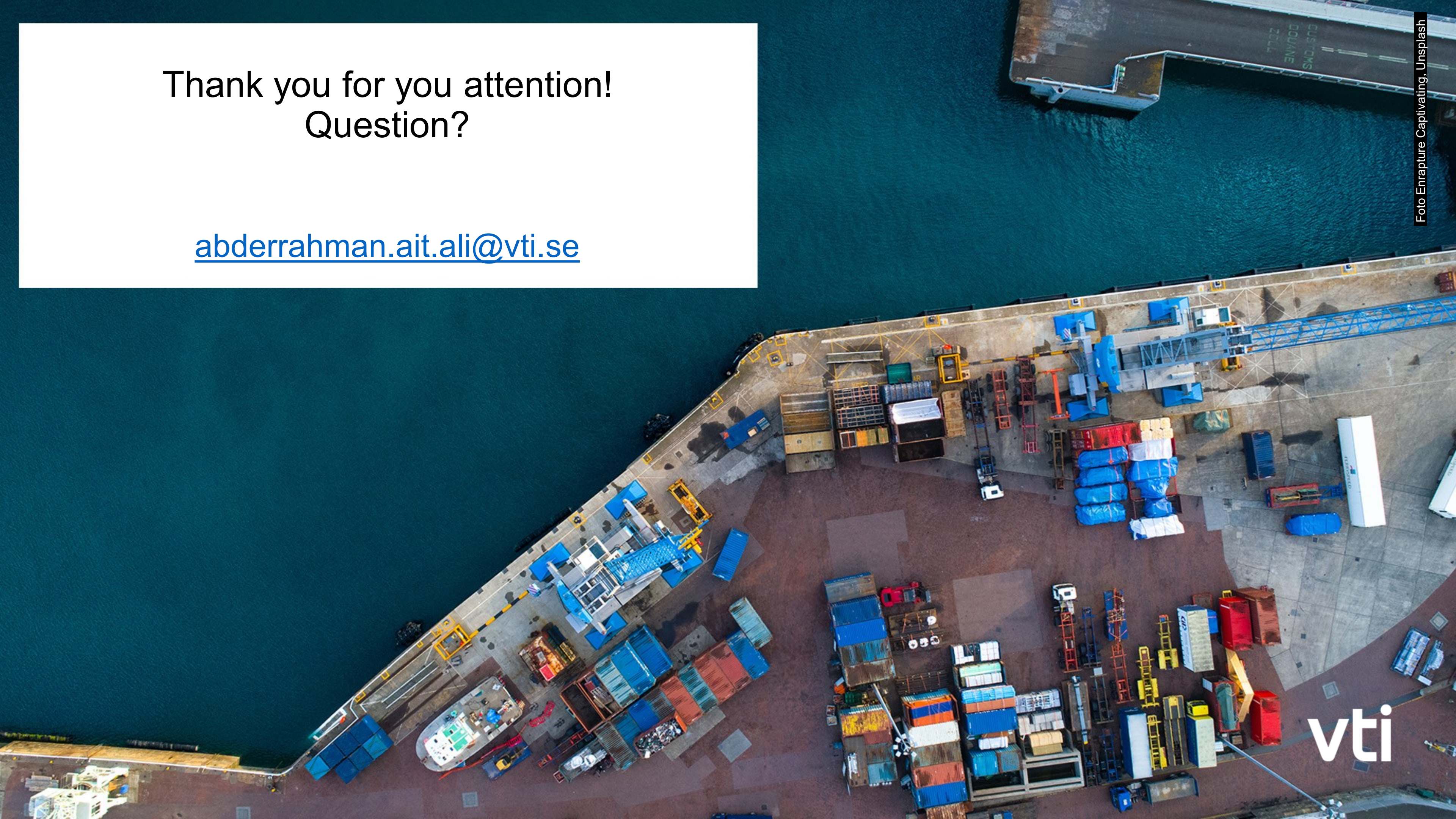

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