(Towards) A better understanding of delays from Switches & Crossings

Grace Mukunzi,
Carl-William Palmqvist,
Kristofer Odolinski

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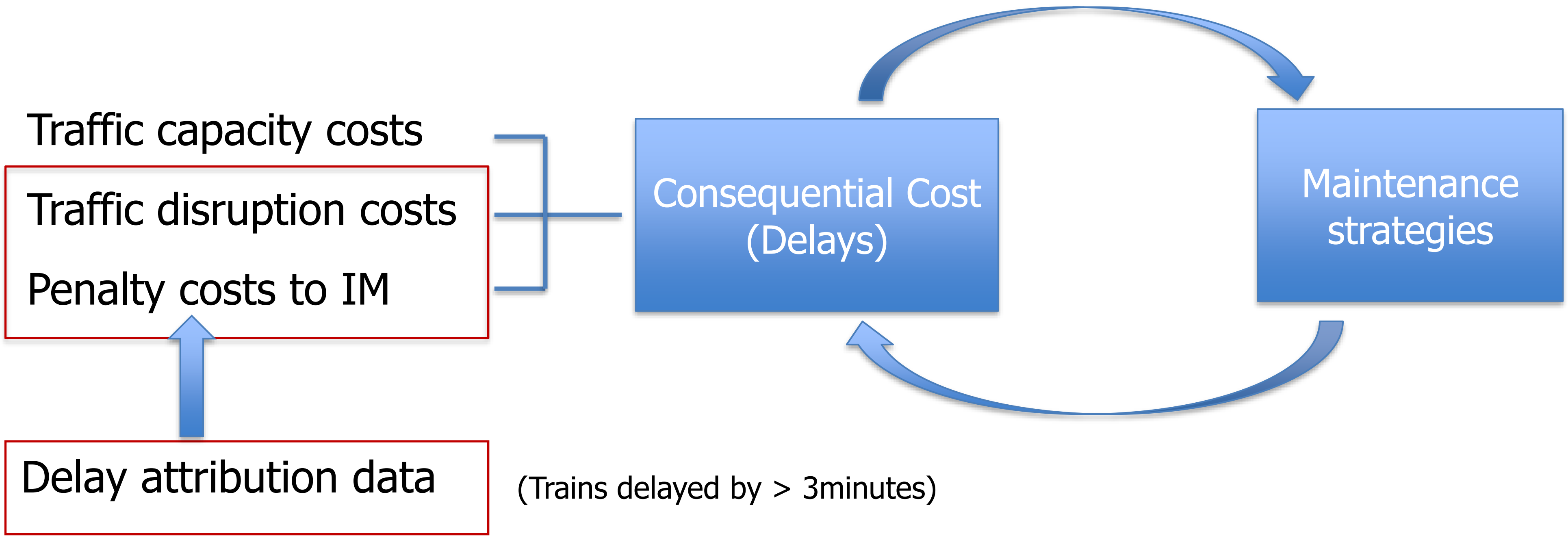
Background: Switches & Crossings

- ‘Points’ along the railway network where tracks merge into, diverge from, or cross each other
- Main function: *network flexibility, capacity & safety*
- Notorious source of disruptions on the railway network

Miantenance of Switches & Crossings

- Studies combine Life Cycle Cost (LCC) and Reliability analyses to determine the most optimal and cost-effective maintenance strategies. (Ait-Ali et al., 2024; Odolinski et al.,2023).

LCC Nissen (2009) = (Acquisition + Maintenance + Consequential) cost



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Study aim and research questions

The overall goal of the study is to determine the levels of maintenance required to keep disruptions from switches and crossings minimal

RESEARCH QUESTIONS

1. To what extent are delays underreported/estimated?
2. What is driving switch failures (and associated delays) on the Swedish railway network?
3. What is a better way to estimate the delay impact of S&Cs?
4. How should S&C maintenance strategies change to reduce disruptions ?

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Method overview

RQ1:To what extent are delays under accounted?

A0:
Aggregate switch attributed delays

A1:
Aggregate all delays conditional upon having a switch failure

A2:
Causal inference by propensity score matching

LUPP

LUPP + OFELIA

LUPP + OFELIA+ SHMI

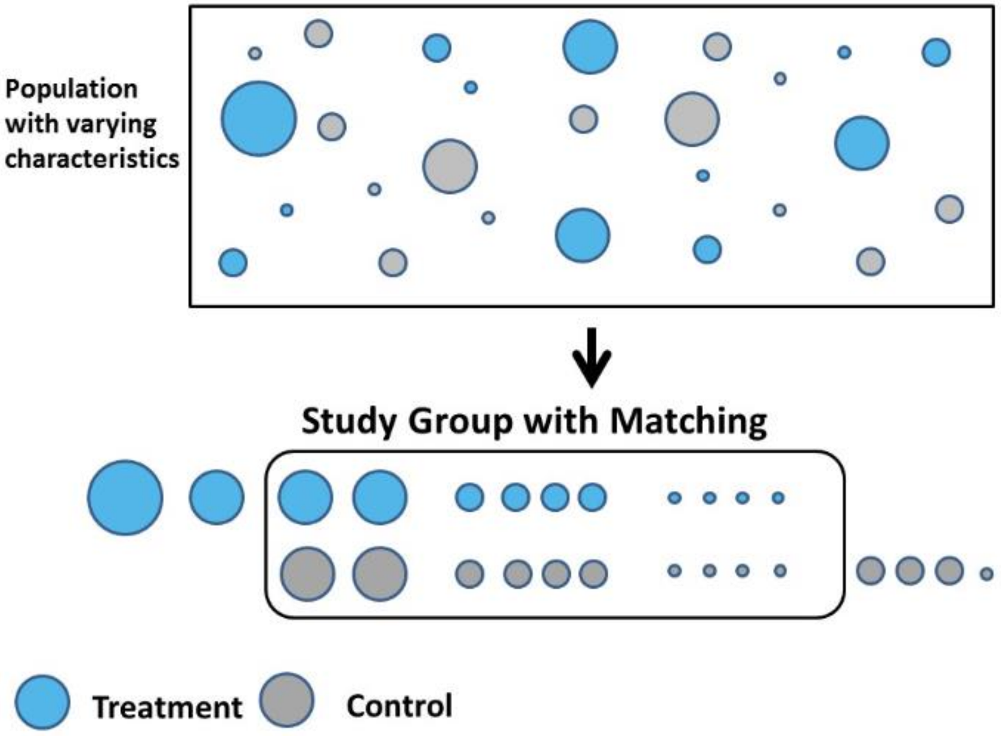
RQ2: What drives switch failures?

Visual Graphical Analysis

Negative Binomial regression

OFELIA+ KONFIGURATION + SHMI

Propensity score matching



https://ar.inspiredpencil.com/pictures-2023/propensity-score

- ❑ Causal inference technique
- ❑ Used in medical studies in non-randomized trials
- ❑ Aims to create control subjects from observational data

Propensity score matching

- Step 1: Propensities are computed as the logistic probability of a switch failing (treatment)

$$ps_i = \Pr(T_i = 1) = \frac{e^{\hat{B}x_i}}{1 + e^{\hat{B}x_i}}$$

Where ps_i is the is the propensity score for the i-th observation and T_i is a binary variable representing the treatment assignment (switch failure) and $\hat{B}$ is estimated from the logistic model.
Independent variables used : Average maximum daily temperature, Average maximum snow depth, track type, percentage of freight trains & total trains

- Step 2: Observations in the control and treatment groups are subsequently matched based on Equation 2

$$min|ps_i - ps_j|$$

Where psi is the propensity score for an observation in the treatment group and psj is the propensity score for an observation in the control group.

- Step 3: The average effect is determined as the mean difference in outcome (Average delay minutes per train) across all pairs. A paired t-test is used to evaluate the statistical significance of the difference

$$y_{1i} - y_{0i} = y_i - y_j$$

- Step 4: Use a paired t-test to evaluate difference in the outcome variable (Average delay minutes per train) for the treatment and control group

$$Total\ delays = Average\ Delay\ Impact * \sum_{m=1}^{n} Number\ of\ delayed\ trains_{\ m}$$

Where,m, is a section on the network with a faulty switch.

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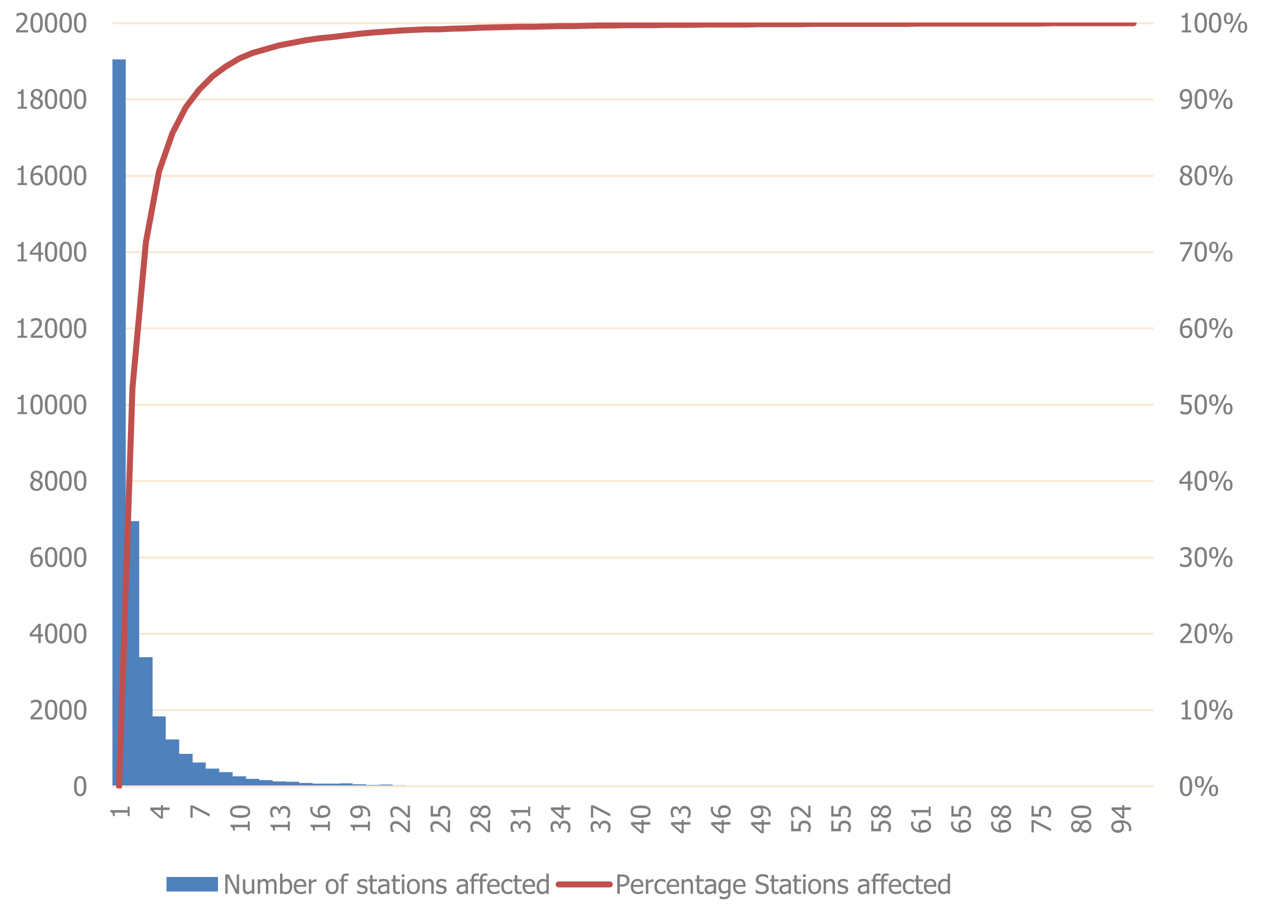
INSIGHTS RQ1

Distribution of the number of stations affected by a switch failure



- ❑ 52% of failures affect only one station
- ❑ 19% affect two stations,
- ❑ 9% affect three stations,
- ❑ 5% affect four stations and
- ❑ 3% affect five stations.

Overall, up to ~ 90% of all switch failure events affect five stations and below

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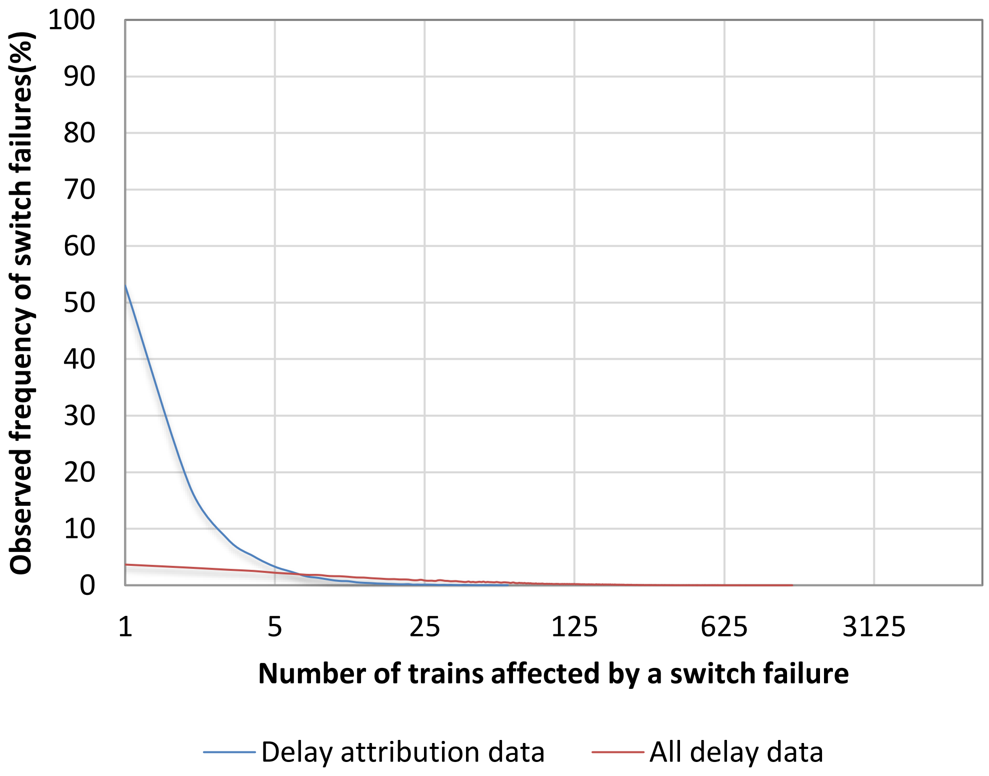
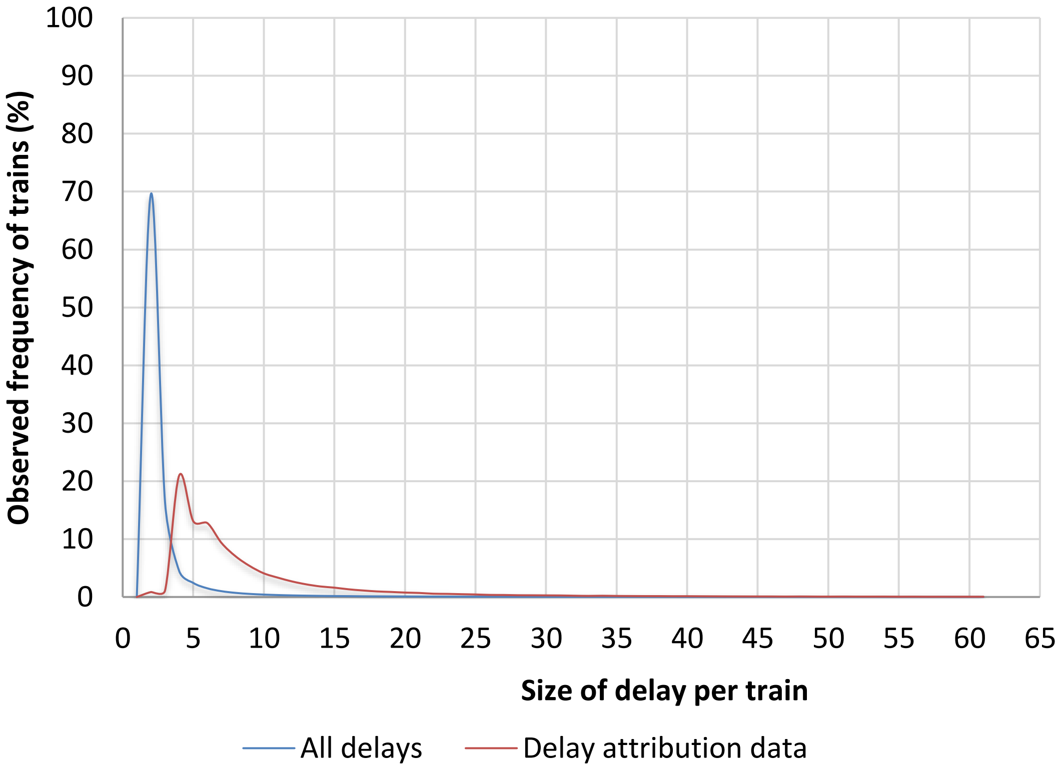
Distribution of the number of trains affected by a switch failure & the delay size

- ❑ For the period 2001 – 2020; 36,479 switch events in LUPP vs 185,225 switch failures in the event report database (Ofelia)
  - ✓ Computations based on delay attribution only account for the impact of 19.7% is accounted for.





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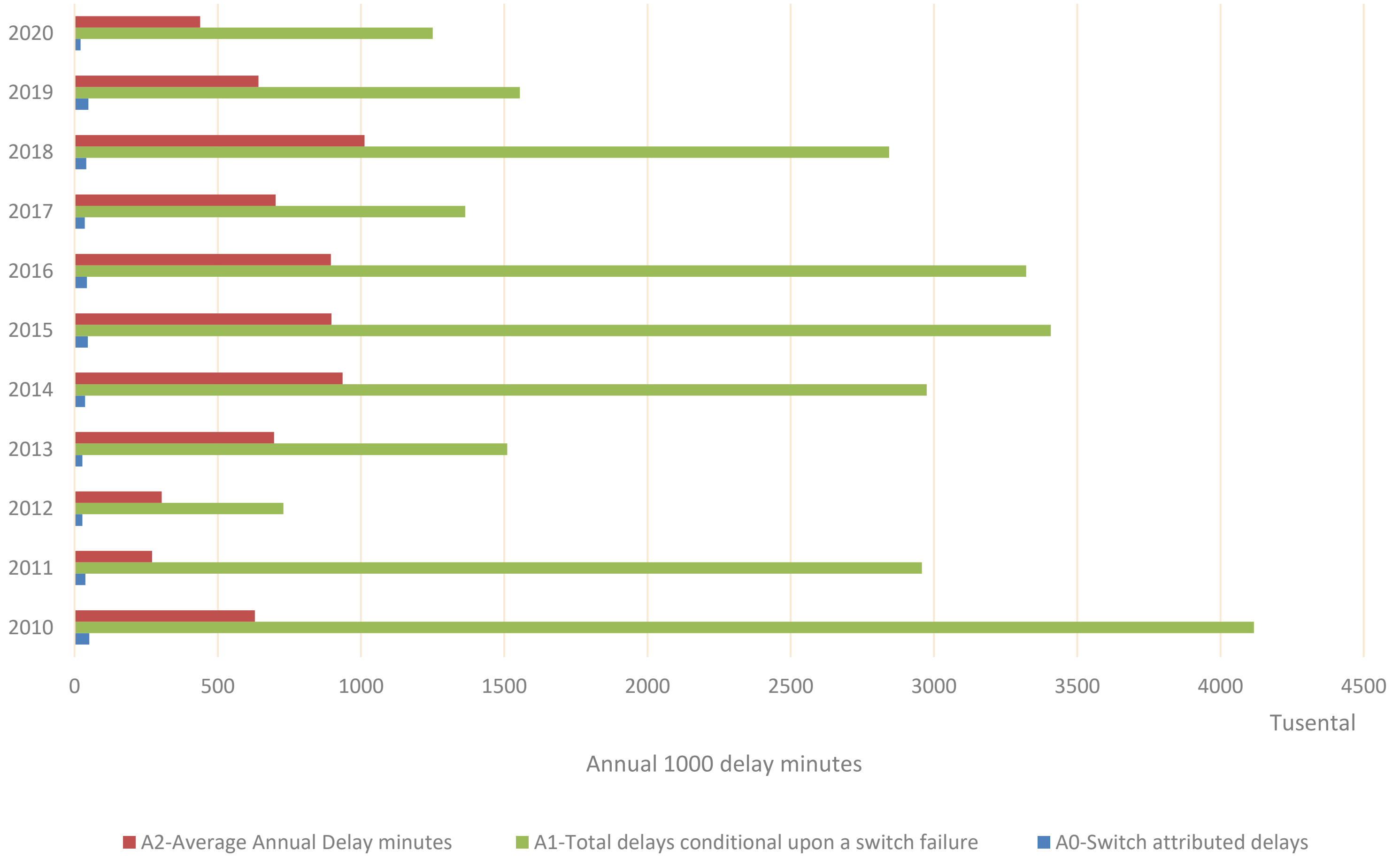
Comparison of estimates from different approaches



- ❑ Average delay per train = 2.3 minutes (Causal inference)
- ❑ Switch attributed delays = 6.4% Total delays conditional upon a switch failure
- ❑ Switch attributed delays = 18% Average annual delay minutes

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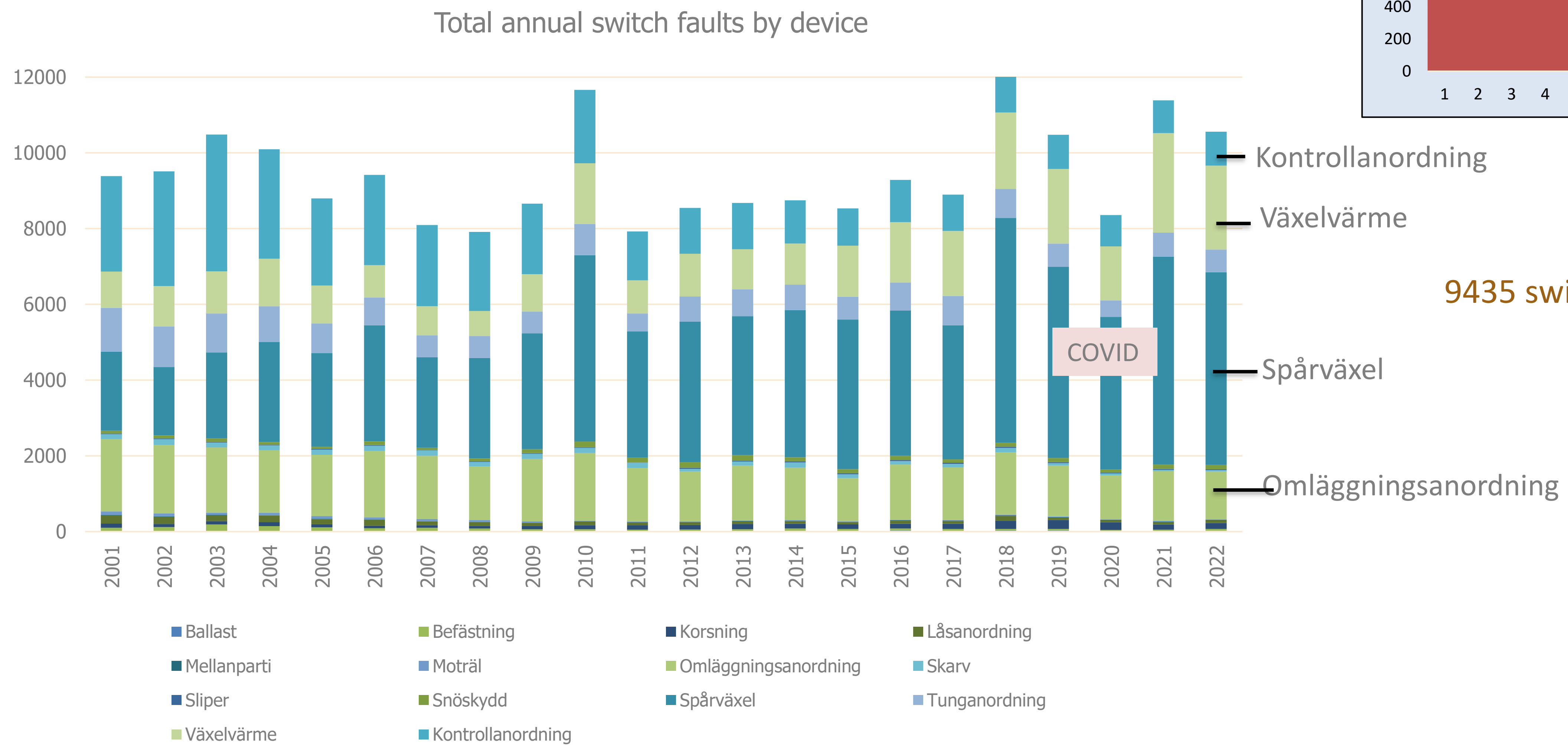
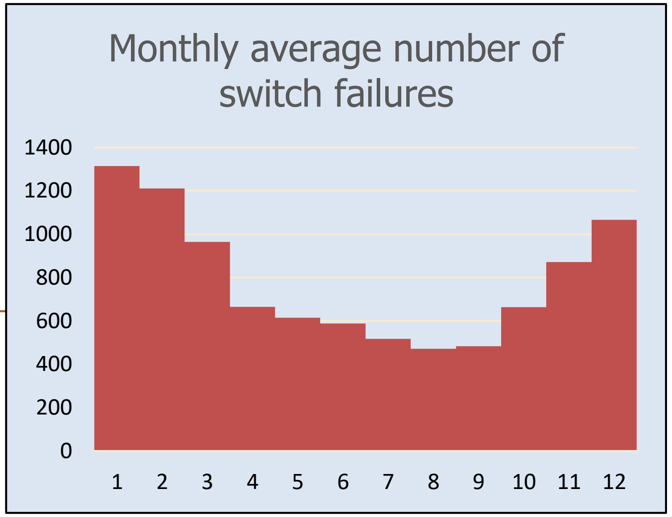
INSIGHTS RQ2

Annual & monthly variation of switch failures





9435 switch faults per year

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Highest switch failure rates on the swedish railway network

	Station	Nr_Switches_2017	Nr_Switch_Failures	Failure_Rate
1	Laduberg	4	18	4.500
2	Mo grindar	2	9	4.500
3	Sävastklinten	4	18	4.500
4	Sandträsk	4	17	4.250
5	Kopparåsen	8	31	3.875
6	Löten	2	7	3.500
7	Ripats	10	34	3.400
8	Lakaträsk	10	32	3.200
9	Stordalen	6	17	2.833
10	Gullträsk	8	22	2.750
11	Höör	14	35	2.500
12	Tågarp	4	10	2.500
13	Träskholm	4	10	2.500
14	Rensjön	12	29	2.417
15	Ljuså	6	14	2.333
16	Isätra	4	9	2.250
17	Östra Grevie	4	9	2.250
18	Via	6	13	2.167
19	Järneträsk	4	8	2.000
20	Koskivaara	8	16	2.000

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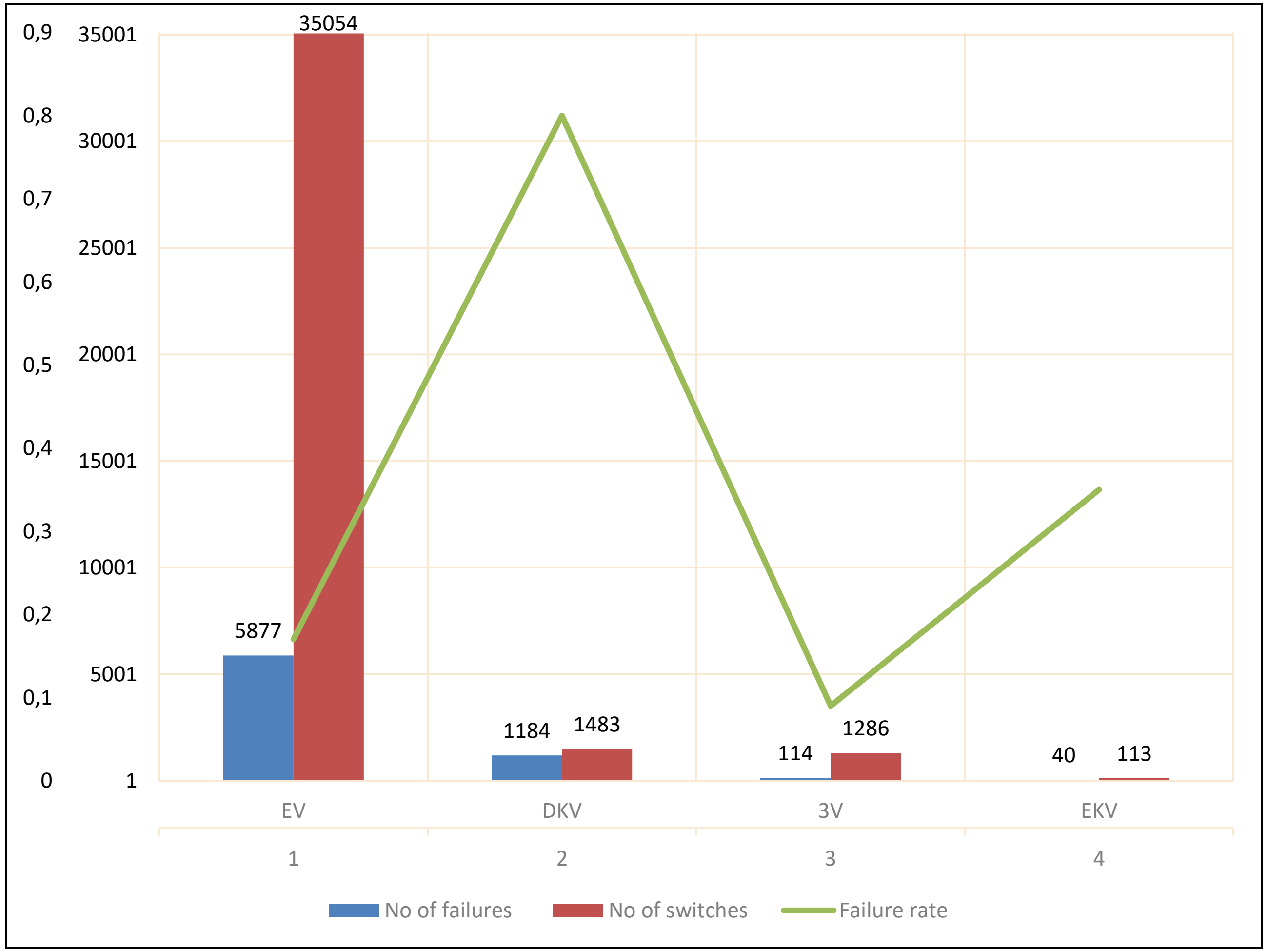
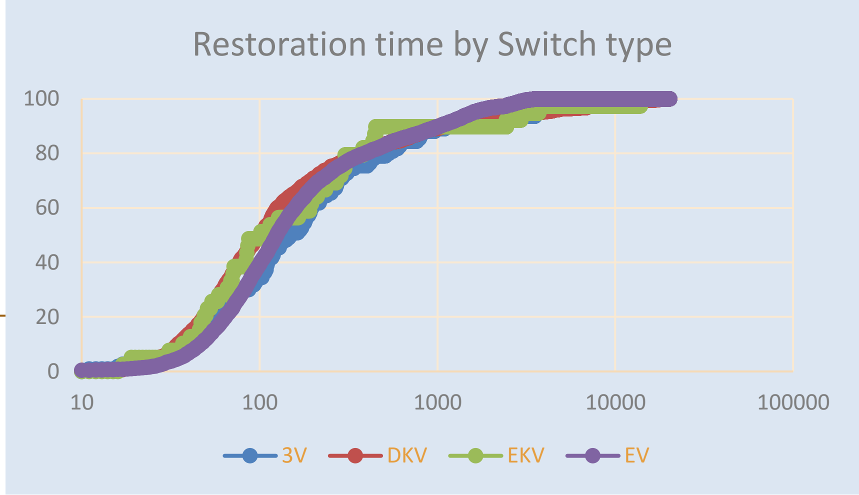
Delay risk due to switch failures (year 2017)

	Station	Number of switches	Number of switch failures	Switch failure rate (FR)	Number of trains (T)	FR*T
1	Tomteboda övre	52	72	1.385	292786	405509
2	Karlberg	68	88	1.294	269618	348886
3	Skavstaby	32	39	1.219	180528	220064
4	Stockholm C	248	215	0.867	214037	185570
5	Solna	102	73	0.716	248556	177966
6	Årstaberg	14	12	0.857	200177	171552
7	Höör	14	35	2.500	67215	168038
8	Flemingsberg	34	42	1.235	132608	163771
9	Älvsjö	134	92	0.687	194398	133551
10	Huvudsta	16	29	1.813	69338	125710

Failure rate of switches by type





- DKV (Dubbel korsningsväxel) have the highest failure rate
- No major difference in restoration time

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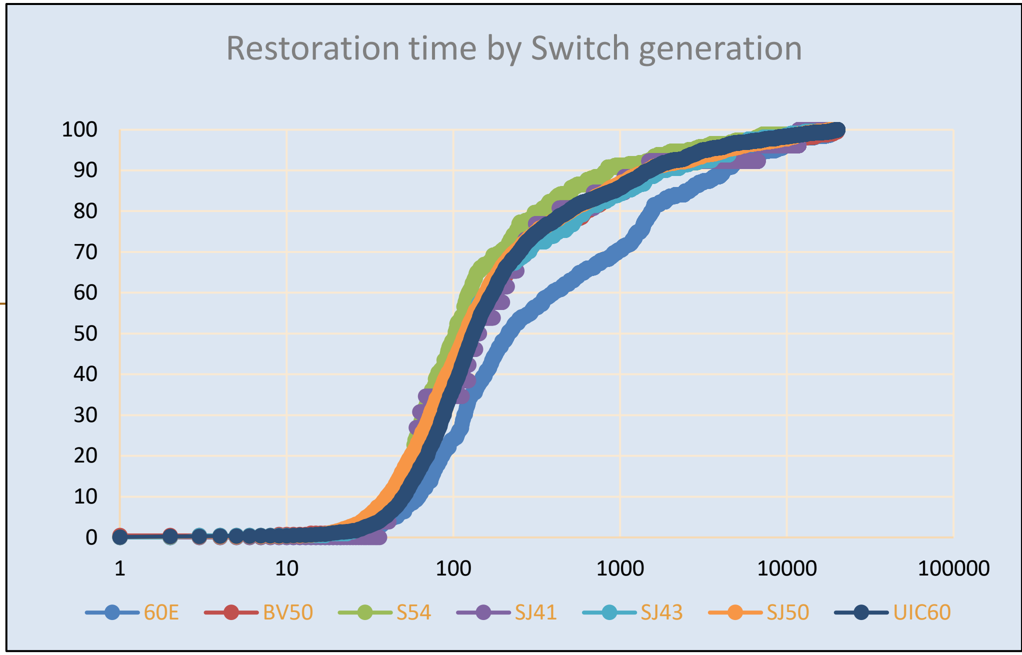
Failure rate of switches by gen.



- S54 have the highest failure rate
- Restoration time for S54 switches > = +100 minutes Restoration time for 60E

Summary & Next steps

- Reliance on delay attribution data results in a substantial under-estimation of S&C delay impact
- There is evidence of weather (cold), size of station (load) driving switch failure, switch type

NEXT STEPS

- Devise a method to systematically define the impact of a switch
- Relative influence of different factors of influence

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Thank you for listening!