STAPLA-F research report

Summary

This research report documents the findings from the pre-study project STAPLA-F, conducted by Linköping University and Trafikverket via the research program KAJT. The purpose has been to investigate how strategic facility planning for balancing of maintenance and train traffic could be done, especially regarding switches and crossings (S&C). The project has also investigated the potentials for network simplifications and the removal of (redundant) S&C. Specifically, the station Katrineholm have been used as a case study.

The results show that the economic potential for reducing the S&C maintenance spending can be in the range of 10% for midsize and larger stations, which translates to 70-80 MSEK per year, and that net traffic delays can be reduced by removal of redundant S&C. Furthermore, this is an interesting research problem, which has not yet been addressed in the research literature. Hence, it is recommended to continue with a PhD research project.

Contents

1 Introduction

The cost for maintaining railway infrastructure has steadily been growing, which mostly is due to an increase in traffic load and previously neglected maintenance. However, there is a possibility to limit and even reduce the maintenance volumes by simplifying the network and removing some of the (redundant) components. The question is how such network simplifications can be done in accordance with the train traffic requirements.

Some network components are crucial for both the traffic, the availability and the maintenance volumes. For example, more switches will give better flexibility for the train traffic, but also an increase in maintenance (and during the maintenance activities the traffic capacity is reduced). Therefore, it is an important strategic decision – both for traffic and maintenance – how the network is designed and planned for such critical components.

Examples from Japan, The Netherlands and England show that savings can be achieved by reducing the number of switches – and that such network changes may have little or even positive effect on the train traffic. In Sweden these questions have not been studied in a thorough and systematic way.

The pre-study project STAPLA-F has been conducted during 2018 in order to study these issues. The goals have been: to investigate and document the state of knowledge concerning reduction of maintenance critical components; assess the potential for such reductions in Sweden while considering the benefits of these components (e.g. concerning capacity, redundancy and robustness); and to prepare for a possible PhD project continuation.

The planning problem concerns traffic network and methods for evaluating the interaction of component availability, maintenance and routing of trains. The focus is on normal traffic trains but may also include positioning movements (to/from parking and train service areas) and locomotive recoupling from one side of the train to the other – when taking place on the central areas of traffic stations.

We do no study parking tracks and shunting yards. Although savings may be easier to achieve at such areas (if there are many redundant tracks), the dimensioning problem for number of tracks and switches are less demanding from a research point of view, since the traffic considerations are less complicated. For the same reason we do not consider where to have non-electrified side tracks for temporary parking of working machines, even though the availability of such tracks will affect the efficiency for the maintenance contractors.

The focus will be on mid-size and large stations, where several traffic flows interact. Interesting stations can be junctions between several lines, either with mostly through traffic (e.g. Katrineholm) or with originating/terminating traffic (e.g. Gävle and Sundsvall). The latter often have terminal areas and/or rolling stock service/repair workshops which means that movements to/from these areas should be considered. Other interesting cases are stations with a mixture of passenger and freight traffic (e.g. Hässleholm and Borlänge) and ultimately very large mixed-traffic stations like Stockholm and Göteborg.

The project has gathered data and statistics concerning the infrastructure, components and populations, maintenance volumes, failure statistics and actual switch usage – as reported in Section 2. Tools and programs for analyzing and visualizing the data has been developed and used. The station Katrineholm has been studied more closely – as reported in Section 3. A literature survey of research publications has been done, which is documented in a separate working paper and summarized in Section 4. Finally, the results and conclusions are presented in Section 5.

2 Data and statistics

2.1 Infrastructure data and populations

Trafikverket has responsibility for the national Swedish railway. It consists of about 14 200 km track, of which 12 400 km (87%) is electrified and 9 000 km (63%) are single track. There are in total 15 200 switches and crossings (S&C) of which TrV owns about 11 000, and 7 500 are heated (Trafikverket - webpage, 2018). The number of TrV owned switches that are in normal main track ("nhsp"), alternate main track ("ahsp") and side track ("ssp") are about 4700/2700/4000.

The traffic network is divided into line types ("bantyp") according to Table 1. In this study we will focus on line types 1—3, which consists of 10 500 km track and 8 400 S&C – further reduced to 9 300 km track and 6 000 S&C when disregarding side tracks. (The latter figure also corresponds to the number of delay causing S&C for line types 1—3.)

Table 1: Line types and statistics (BIS, 2018)

Line type	**Definition**	**Track length [km]**	**S&C [count]**
1	Metropolitan areas	1 500	2 200
2	Primary main lines	4 300	3 400
3	Lines with extensive freight and passenger traffic	4 700	2 800
4	Commuting lines	2 000	800
5	Other industrial lines	1 500	600
6	Little or no traffic	300	100
98-99	Unclassified	300	1 100
	Sum	**14 600**	**11 000**

2.2 Maintenance volumes / budget spending

Trafikverkets annual reports for 2015-2017 shows that the total spending on railway maintenance is 4 700 – 4 900 MSEK, with an additional 2 200 – 2 600 MSEK for renewals. The maintenance volume is divided into 12 different categories of which three are interesting here: S&C ("spårväxlar"), fixed basic maintenance ("fast del, basunderhåll") and winter ("vinter"). According to a study of six maintenance contracts (Gustafsson, 2018) done 2012, about 26% of the figures for fixed basic maintenance and winter can be attributed to work on switches[1]. Thus, we can calculate the average maintenance spending for S&C for the years 2015-2017 as shown in Table 2.

Table 2: Maintenance volumes [MSEK]

Category	2015	2016	2017	Average	S&C share
S&C	339	413	388	380	380
Fixed	1 129	1 115	1 373	1 200	310
Winter	324	314	287	300	80
				Sum	**770**

If this figure is evenly spread over 8 400 S&C's we get an average spending of 92 KSEK/S&C. However, more work will be done on highly utilized switches and less on peripheral ones. We estimate the cost range for yearly maintenance spending per S&C to be 40-200 KSEK and will use 100 KSEK as the maintenance cost saving that can be achieved by removing a switch (in main track for line types 1—3).

Maintenance spending for tracks is larger than for S&C. The yearly budget is in the range 1 800 – 2 500 MSEK, which gives about 140-400 KSEK/km. Reduction of tracks is however harder to achieve without impairing the train capacity. Hence, our focus will be on S&C.

2.3 Failure statistics

Failure statistics from Ofelia for line types 1-3 (which stands for 80-90% of all incidents and delays) have been analyzed for the period 2012-2017. Each failure report is counted as an incident, and for each incident the resulting train delay, the response time and the repair time is reported. However, the severity of the incidents range from minor warnings, over malfunction to serious breakdowns. Thus, many incidents will have no impact on the trains, while others cause large delays. To get a better understanding for the delay distribution we divide the incidents into the following delay classes:

- 0: no train delays
- ¼: 15-minute delays (all incidents in the range 0-30 minutes)
- 1: one-hour delays (range 0,5-1,5 hours => bin size 1)
- 2,5-hour delays (range 1,5-3,5 => bin size 2)

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[1] The share of fixed maintenance and winter work for tracks was not documented in the interview. Hence, we can only say that it is in the range 25-75%.

- 5-hour delays (range 3,5-6,5 => bin size 3)
- 10-hour delays (range 6,5-13,5 => bin size 7)
- 20-hour delays (range 13,5-26,5 => bin size 13)
- 40-hour delays (range 26,5-53,5 => bin size 27)
- 80-hour delays (range 53,5-106,5 => bin size 53)
- L: all delays longer than 106,5 hours

In Table 3 the incident counts are shown for S&C, track, track circuit (TC) and contact wire (CW) failures. First, we note that more than 60-70% of all S&C, TC and CW incidents have no impact on the train delays, and that about 80% or more of all S&C, track and TC incidents give train delays of less than 30 minutes. As a consequence, we first disregard all incidents in delay class 0 and ¼, since they distort the incident counts. Furthermore, we skip delay class L since these incidents might cause delays of several hundreds of hours, which distorts the delay volumes.

Table 3: Incident counts and shares per delay class.
Average values for years 2012-2017

	All	0	¼	1	2,5	5	10	20	40	80	L
S&C	7294	5424 (74%)	1005 (14%)	452 (6%)	217 (3%)	94 (1%)	58 (1%)	28	12	4	1
Track	3213	1495 (46%)	1051 (33%)	239 (7%)	172 (5%)	106 (3%)	80 (2%)	44 (1%)	17	5	4
TC	3079	1839 (60%)	673 (22%)	323 (10%)	147 (5%)	54 (2%)	27 (1%)	10	4	2	1
CW	1018	691 (68%)	51 (5%)	49 (5%)	48 (5%)	37 (4%)	48 (5%)	40 (4%)	30 (3%)	16 (2%)	9 (1%)

The delay volumes for delay classes ¼-80 are plotted in Figure 1. We see that the delay volume for S&C failures are evenly spread in class 1 to 40, while track failures have a max volume in class 10-20. TC failures have the smallest and decaying volume from class 2,5 and upwards, while the CW failures have a large and increasing volume towards the longer delay classes. We conclude that TC and CW failures have the lowest and highest delay impact, respectively.

Figure 1: Delay volume [h] for failures in delay class ¼-80

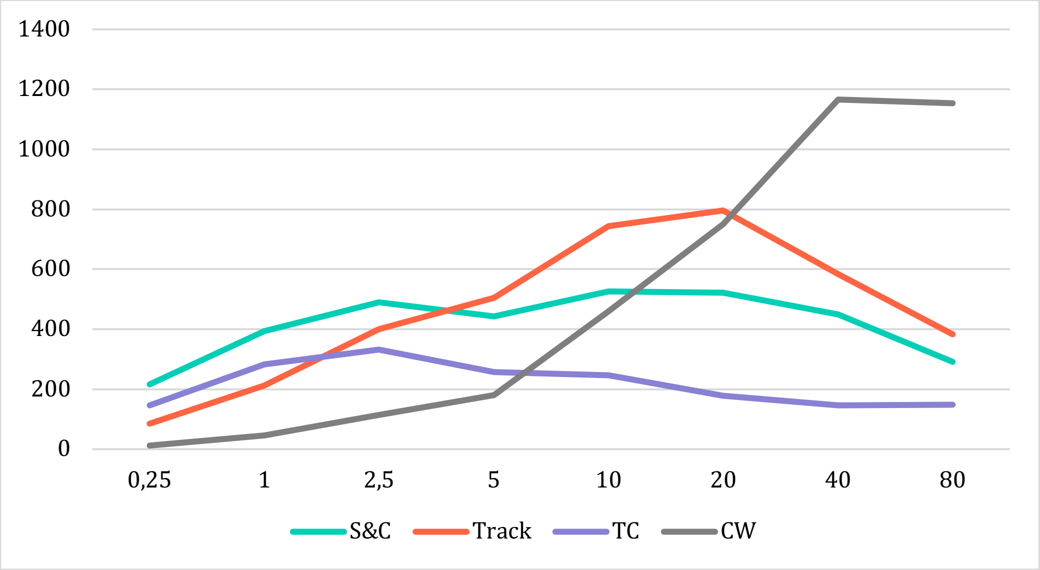


Table 4 gives the yearly incident count and average delay for all failures in delay class 1-80 and ¼-80 respectively. We see that: delay class ¼ has a large influence on the figures; S&C failures are the most frequent; TC failures cause the lowest average delays; and CW failures occur less frequently but have a very large delay impact. The table also reports the population-dependent incident frequency, based on the populations in line types 1-3, as stated in Section 2.1. For S&C we use the number of switches (8 400) as population. For track, TC and CW we use the track length (10 500 km). The values in Table 4 will be used for estimating the failure and delay impact of removing switches.

Table 4: Yearly incident count, average delay per incident and incident frequency. Train affecting failures

	Delay class 1-80			Delay class ¼-80		
	Incidents [count]	**Delay** [h]	**Incident frequency**	**Incidents**	**Delay**	**Inc. freq.**
S&C	864	3,6	0,103 [switch^{-1}]	1868	1,8	0,222
Track	663	5,5	0,063 [km^{-1}]	1714	2,2	0,163
TC	567	2,8	0,054 [km^{-1}]	1240	1,4	0,118
CW	267	14	0,0254 [km^{-1}]	318	12,2	0,0302

2.4 Switch usage statistics

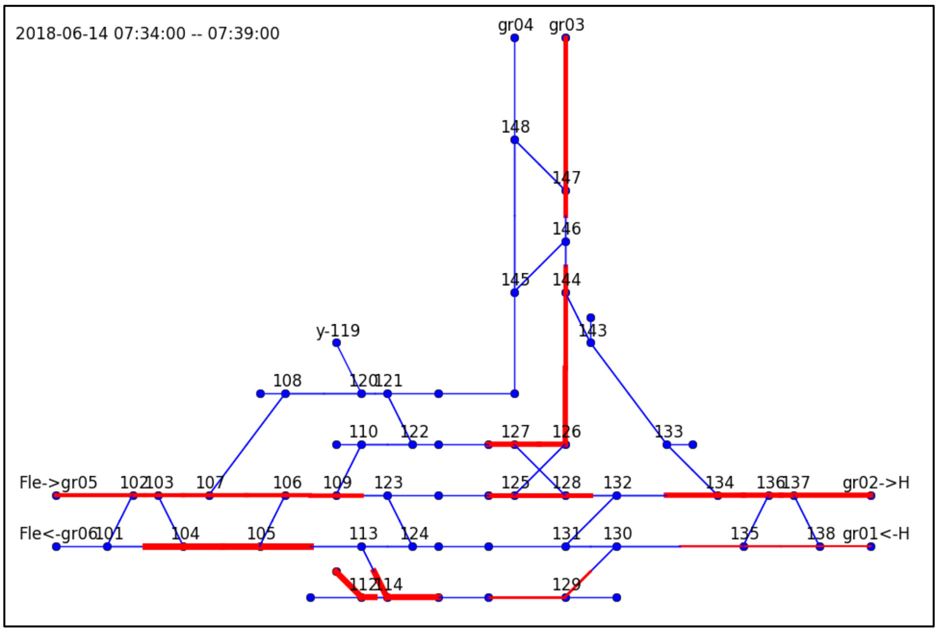
DS-Analys is a tool that collects real-time data from the traffic management systems in Gävle, Stockholm, Hallsberg, Norrköping, Göteborg and Malmö. Each switch turn (with turn time) and occupation (together with the current switch position) is logged. Users can collect statistics, download logs, analyse the statistics and compare with failure rates.

In this study, we have worked with logs from Katrineholm that cover a 45-day period between 2018-05-01 – 2018-06-14. Usage statistics have been obtained via spreadsheet analysis (pivot tables), but in addition a Python program has been developed for illustration of the switch occupations. By showing recent occupations with bold lines and thinning them out over a couple of minutes it is possible to visualize the train movements. This gives a view of actual train routes, but also other switch occupations, caused by track works or spurious track circuit indications etc.

An example of the program output is shown in Figure 2. We see one train that has come from Norrköping and has just passed switch 127 (this train lacks indication from 146). Also, there is a train that has come from Flen and has passed on track 3 towards Hallsberg (lacking indications from 123 and 132). Finally, there is a train from Hallsberg that has been routed over track 1 and now is leaving towards Flen (currently at switch 104). For the last train there is an erroneous occupation on switch 112 and no reporting from 113.

Unfortunately, there are no occupation reporting from switches 123, 124, 131 and 132. Also, occupation records are frequently missing from 146 and 109.

Figure 2: Screen shot from DSA visualisation tool.



3 Case study of Katrineholm

The station Katrineholm has been chosen as case study. It is an important junction that connects Södra Stambanan to Västra Stambanan. The geographic layout is shown in Figure 3, while the logical structure (from BIS) is depicted in Figure 4 – note that the latter is rotated 180 degrees as indicated by the compass north indications.

Figure 3: Katrineholm, geographic layout

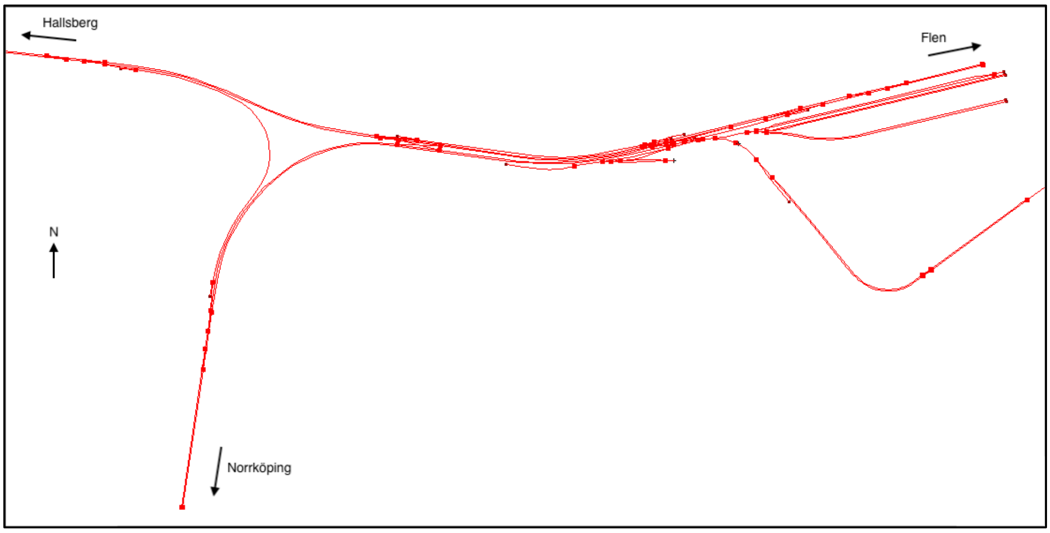
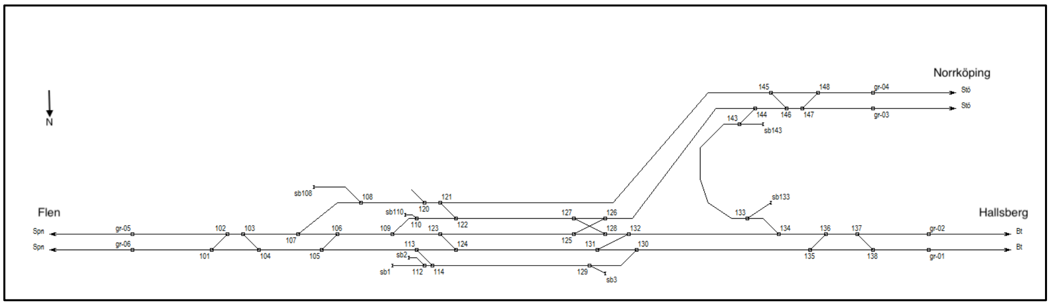


Figure 4: Katrineholm, logical structure



In this study we disregard the railway yard and focus on the traffic network. The number of S&C are 38, consisting of 13 crossovers (1 scissor), 6 normal three-way switches and 6 safety switches. The total track length for this part is 7 590 m.

Given the failure statistics for delay class 1-80 in Table 4, we expect to have:

- $38 * 0{,}103 = 3{,}9$ S&C (major delay causing) incidents per year, with an average train delay of 3,6 h;

- $7{,}59 * 0{,}0631 = 0{,}5$ track incidents per year, with an average delay of 5,5 h;
- $7{,}59 * 0{,}054 = 0{,}4$ TC incidents per year, with an average delay of 2,8h.

The S&C failure statistics at Katrineholm (Table 5) for the period 2010-2017 (8 years) shows that there have been 25 actual incidents (=> 25/8=3,1 per year) with an average delay of 3,0 hours (in delay class 1-80). Thus, the aggregated statistics give an estimation error, as compared to actual outcome, of (3,9-3,1)/3,1=26% for the number of incidents and (3,6-3,0)/3,0=20% for the train delays. This is sufficiently accurate for such a small sample size.

Table 5: Failure statistics for delay class 1-80, Katrineholm. First column gives the S&C id number. Data shows average delay [h] with incident count in parentheses.

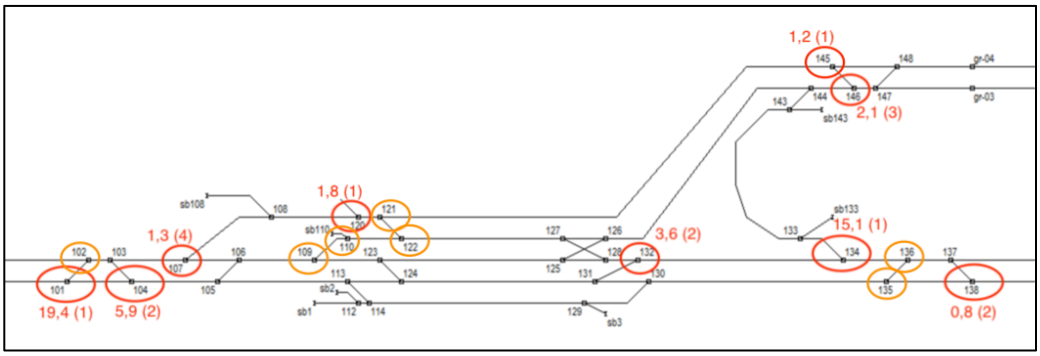
ID	2010	2012	2013	2014	2015	2016	2017	Avg.
101						19,4 (1)		19,4 (1)
102	0,7 (1)							0,7 (1)
102/6/9	1,0 (1)							1,0 (1)
104					0,8 (1)		11,1 (1)	5,9 (2)
107			0,7 (1)	2,2 (1)			1,1 (2)	1,3 (4)
109							0,6 (1)	0,6 (1)
110		0,8 (1)						0,8 (1)
120		1,8 (1)						1,8 (1)
121			0,5 (1)					0,5 (1)
122		0,6 (1)						0,6 (1)
132	2,2 (1)			5,0 (1)				3,6 (2)
134			15,1 (1)					15,1 (1)
135	0,9 (1)							0,9 (1)
136				0,8 (1)				0,8 (1)
138	0,9 (1)	0,7 (1)						0,8 (2)
145	1,2 (1)							1,2 (1)
146				1,1 (2)	4,2 (1)			2,1 (3)
Avg.	1,2 (6)	1,0 (4)	5,4 (3)	2,1 (5)	2,5 (2)	19,4 (1)	3,5 (4)	3,0 (25)

If we do the same calculation using the statistics for delay class ¼-80, we get:

- 8,4 S&C incidents/year, with an average 1,8 h train delay;
- 1,2 track incidents/year, with an average 2,2 h train delay;
- 0,9 TC incidents/year, with an average 1,4 h train delay.

The failure statistics for Katrineholm for 2010-2017 shows 72 such delay causing S&C incidents (=> 72/8=9,0 per year), with an average 1,2 h delay. Thus, the estimation error for incident count is only 7% while it is 50% for the delay. From this we conclude that using average values works reasonably well for delay class 1-80 but less well for delay class ¼-80. Hence a more detailed failure distribution should probably be used when including all delay causing failures. This has not been done in the pre-study and in the rest of this report we will use delay class 1-80.

Figure 5: Delay causing switches, Katrineholm. Red marks S&C with delays > 1 h or more than one incident. Orange marks S&C with one incident and delay < 1 h.



In Table 5 the S&C failure statistics at Katrineholm is presented and in Figure 5 the most frequently failing and high delay causing switches are marked. We see that the variance is high and that highly utilized switches causes the major delays.

We now study the traffic flows through Katrineholm. These have been obtained from track occupancy plans for the week 2018-02-05 – 11. For each 3 h period the number of through (non-stopping), stopping and turning trains have been counted. Trains to/from the Katrineholm yard have been identified and overtaking situations have been found from train numbers that oppose the normal running direction of the tracks. Table 6 gives the weekly train counts in the timetable, while Table 7 shows the traffic flows both in the timetable and as measured in DS-Analys. Finally, Table 8 lists the identified overtaking patterns. The peak traffic load, for any track, for one hour is 5 stops or 3 stops and 3 passes, which gives a train separation of about 10 minutes.

Table 6: Weekly train counts, Katrineholm

	Train counts			
Track	**Through**	**Stopping**	**Turning**	**Sum**
1		195	5	200
2	168	14		182
3	159	200		359
4	204	148		352
5	206	98	5	309
20	26	2		28
Total	763	657	10	1430

Table 7: Traffic flows - timetable vs measured in DS-Analys

Route	**Timetable**		**DS-Analys**	
	Trains per week	**Trains per day**	**Counts (45d)**	**Count per day**
Flen-Norrköping	304	43,4	1838	40,8
Norrköping-Flen	352	50,3	2086	46,4
Flen-Hallsberg	359	51,3	1990	44,2
Hallsberg-Flen	377	53,9	1985	44,1
Hallsberg<->Norrköping	28	4,0	180	4,0
To Katrineholm yard	12	1,7	75	1,7
From Katrineholm yard	12	1,7	75	1,7

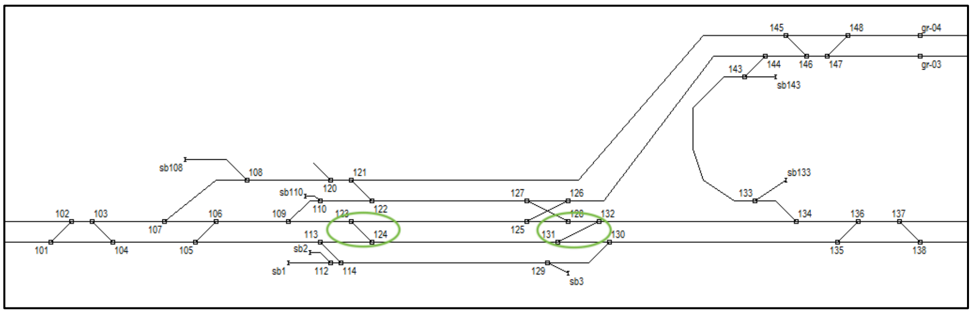
Table 8: Overtaking patterns

Route	**Track number**		**Count per day**
	Waiting train	**Passing train**	
Flen-Norrköping	4	5	1
Flen-Hallsberg	2	3	1
Flen-Hallsberg	4	3	2
Hallsberg-Flen	1	2	4
Hallsberg-Flen	3	1	1

Based on these statistics and the necessity to allow single track traffic on connecting lines, all S&C that must be present (including safety switches) have been identified. Two crossovers, namely 123-124 and 131-132 (see Figure 6), seems redundant and might be considered for removal.

The crossovers 123-124 and 131-132 were introduced some 10 years ago, to allow for overtaking situations in the direction Flen-Hallsberg without disturbing the meeting traffic (Hallsberg-Flen). As shown in Table 8, there is one overtaking per weekday in that direction (row 2) for the 2018 timetable. However, in this case (train numbers 4461 and 10439) there are no concurrent trains in the opposing direction and the separation to previous/subsequent meeting trains are 9-10 minutes. Thus, for undisturbed traffic or small delays these inner crossovers are not necessary, but for larger disturbances they will be beneficial. In this pre-study, we have neither attempted to quantify this effect, nor investigated how often parallel overtaking and meeting on tracks 1-3 have been utilized in timetables or operational situations. This should be done before any such modifications are decided.

Figure 6: Possible S&C reductions



We can however estimate some other consequences of removing the four switches 123-124 and 131-132. They represent about 1/10 of the switches at Katrineholm and, based on the incident frequency, the number of incidents might be reduced by 4 * 0,103 = 0,4 per year. If each incident gives an average delay of 3,6 h, the yearly reduction of S&C caused delays is

$$d^{gain} = 0{,}4 \times 3{,}6 = 1{,}4 \text{ h.}$$

This is also supported by the actual failure outcome at Katrineholm (see Table 5), which shows that switch 132 has had two failures during eight years, with an average delay of 3,6 h.

On the other hand, these switches might have a positive effect when track or track circuit (TC) failures occur – but not for catenary wire incidents. As a liberal estimate we assume that the delays will increase by 1 h for half of the track and TC failures at Katrineholm if switches 123-124 and 131-132 are removed, which amounts to:

- Track failures: 0,5 / 2 = 0,25 incidents with 1 extra hour => 0,25 h
- TC failures: 0,4 / 2 = 0,2 incidents with 1 extra hour => 0,2 h

Thus, the yearly delay increase of not having these switches is estimated to

$$d^{loss} = 0{,}25 + 0{,}2 = 0{,}45 \text{ h.}$$

All in all, the net delay reduction ($d^{gain} - d^{loss}$) if removing these switches can be estimated to 1,4 - 0,45 = 0,95 h or 57 minutes per year.

It is possible to use Trafikverket's cost benefit tools (TrV ASEK, 2018) and apply this delay reduction value, equally distributed over fast trains, passenger trains and freight trains on the Flen-Hallsberg traffic, to get an estimated yearly socio-economic saving. However, the net effect on each train is so small that the socio-economic effect is negligible.

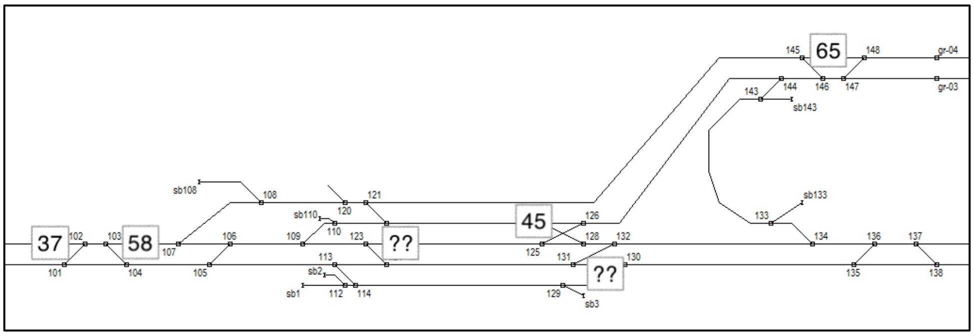
Note, that an extra train run time or additional delay of 1 minute for the parallel overtaking situation and meeting (as discussed previously) that happens more than once a week will balance out the net delay reduction of 57 minutes.

The yearly maintenance cost saving can be estimated to 4 * 100 = 400 KSEK, while the actual removal cost amounts to about 4 * 100 = 400 KSEK for the physical work with an additional 1 MSEK for adjusting and redesigning the signaling system. Thus, the economical pay-off time is about three-four years if doing the facility changes on their own. The pay-off will be immediate if doing the changes in conjunction with other projects such that the re-signaling costs can be shared.

Another possibility that can be considered, is to inactivate all predefined routes and automatic functions in the traffic management system that use the switches in their diverging direction. Thus, they will stay straight during normal traffic situations but will still be available for use during disturbed situations via manual route setting. The cost for such a “soft removal” is very low and can be implemented quickly for evaluation purposes. However, hardware faults may still occur with this option.

Finally, the occupation and switch turn data from DS-Analys (from the 45-day period 2018-05-01 – 2018-06-14) have been analysed to see if any interesting or unusual patterns occur. As noted before, there are some switches that have no reported occupancies – particularly 123-124 and 131-132. This is unfortunate since these are the switches that have been identified for possible removal, and we would like to see how often train passages occur over the diverging direction for them. Other switches that have few passages in their diverging direction are marked in Figure 7. Switches 101-102 and 125-126 have on average less (or equal) than one train passage per day recorded, and therefore they might be considered for removal. The crossover 101-102 is however needed for single track traffic on the line to Flen and should therefore be kept.

Figure 7: Switches with few passages in diverging direction. Number of occurrences for the 45-day period 2018-05-01 -- 2018-06-14.



The crossover 125-126 is not used in any timetabled routing patterns but could be beneficial in disturbed situations. The 45 usages (see Figure 7) have been studied with the visualization tool and it shows that in about 75% of the cases the 125-126 crossover is necessary to have – for example to solve an overtaking situation for two trains coming from Norrköping and going towards Flen, while meeting another train in the opposite direction. Without 125-126 the overtaking would have to be done at another station, which might cause a delay increase. For this reason, we recommend keeping this crossover switch.

Switch turn data in DS-Analys shows considerably more turns for switch 124 and 131 than 123 and 132. After consulting signaling expertise it has been found that this is due to an interlocking function that tries to achieve maximum side protection for routes to and from track 1. However, there is sufficient safety distances available for allowing concurrent train approaches even if the switches would be removed. In any case it is preferable to avoid excessive amounts of switch turns since they may cause an increase in maintenance costs and/or risk for failures. (The latter has not been observed in the failure statistics for Katrineholm, neither for delay causing failures (see Table 5) nor for incidents with no impact on trains.)

From this case study of Katrineholm, we draw the following conclusions:

- The aggregated incident frequencies and average delay figures in Table 4 correlate well with the detailed statistics at Katrineholm for delay class 1-80.
- Even though Katrineholm has a rather clean and simple layout, four switches (two crossovers) have been identified that might be possible to remove in the future. The delay reductions due to fewer S&C failures are larger than the delay increases due to less flexibility during track and track circuit failures at this station. However, the yearly delay change is small and the net socio-economic effect is negligible.
  A closer study of the usefulness of these switches – considering traffic usage (both planned and operational) as well as surrounding track layouts – is needed.
- The yearly maintenance cost saving is estimated to 400 KSEK and the economical pay-off time is one to three years depending on whether re-signaling cost is shared with other facility changes or not.
- A manual analysis, as done in this study, is possible to do for stations with relatively simple layout and traffic patterns. For more complex stations and traffic patterns, computational support will be needed.
- The data sources at Trafikverket for failure statistics and switch usages are sufficiently detailed, but some crucial information is sometimes lacking – particularly in DS-Analys. Of great interest would be the coupling of train numbers to the switch data in DS-Analys.

4 Literature survey

The complete literature survey is written in a separate working paper (Kaya, 2018), which we briefly summarize here.

Some conference presentations have treated the ideas of simplification of station layouts – and the importance of designing the network in conjunction with the traffic patterns. In (Weeda & Hofstra, 2008) the separation of train flows are discussed and applied on the Utrecht station, while (Verstegen, 2014) describes a new design philosophy, inspired by lean principles and Japanese practice, adopted in The Netherlands and applied at several different types of stations (Naarden-Bussum, Eindhoven West, Gouda). In some cases, the redesign resulted in a 50-70% reduction of switches, while giving higher train speeds and shorter headways. Thus, the network simplifications can also improve capacity and performance. Some examples of similar work at Network Rail is reported in (Hilary & Smith, 2014), where many switches were identified for removal at the Cumbria Coast, the Tess Yard, and the South Croydon Junction. The methods used in these works have included cooperation of different experts and stakeholders, workshop exercises and manual analysis.

In the research literature we have only found publications that treat various forms of train routing, track and platform assignment. In these works, the infrastructure is fixed, and the problem concerns how to select train routes and schedule the train movements. As for telecommunication networks there are papers that treat the problem of selecting nodes and connections in order to support a certain network load, but then the traffic is treated as continuous flows rather than discrete packets (as needed in the train case).

Although we have not found any research publications concerning network simplifications for train traffic, several interesting modelling approaches have been found, which can be useful when developing quantitative design and analysis tools.

5 Summary and conclusions

This pre-study has focused on the main traffic network of Sweden (line types 1, 2 and 3). The main quantifiable results are as follows:

- The yearly maintenance cost for switches are about 100 KSEK/switch, while track maintenance costs about 200-300 KSEK/km. Although the total maintenance cost is higher for tracks than for switches, there is a greater potential for switch reductions.
- Failure statistics show that the incident frequency for delay causing failures (with train delays between 0,5 and 100 hours per incident) is 0,103 per switch and year. The incident frequency for delay causing track failures is 0,063 per km and year, while for track circuit failures the incident frequency is 0,054 per km and year. The average train delay for these failure types are 3,6 h (switches), 5,5 h (track) and 2,8 h (track circuits).
- The Katrineholm study shows that removal of two crossovers (four switches) might be possible, which is about 10% of the S&C at that stations. For this case a small net reduction of traffic delays can be obtained, estimated to just under 1 h per year. The socio-economic effect of this is negligible.
  The switches are beneficial for overtaking situations in the direction Flen-Hallsberg, with concurrent meetings trains. Although this option is not used in the 2018 timetable, such cases may arise in disturbed situations or in future timetables. This traffic benefit remains to be quantified.
- The saving in maintenance cost when removing two crossovers at Katrineholm is estimated to 400 KSEK per year. The pay-off time for the removal is one to three years depending on whether the re-signaling cost is shared with other facility changes or not. “Soft removal” by avoiding use of these switches in the traffic management system can also be considered.

If the simplifications at Katrineholm have a net benefit and gives a representative reduction volume, they indicate an economical potential for reducing maintenance spending on switches and crossings of about 10% for midsize and large stations. This translates to 70-80 MSEK per year. Furthermore, such switch removals can reduce the net traffic delays – albeit with a small amount. International examples show even more promising results and larger benefits for complicated station layouts.

The pre-study has shown that manual analysis is possible to perform on simple stations with a clear layout and traffic patterns. For more complicated cases, computational support would speed up the analysis work and give a more accurate foundation to support future redesign decisions.

There is an interesting research problem to study, which has not yet been addressed in the research literature. Thus, there exists an identified research gap. Specifically, we recommend studying methods that from given traffic requirements and an existing station layout can identify the most promising or even optimal simplifications and redesigns of mid-size and large railway stations. The traffic requirements should include normal traffic flows, meet/pass handling during disturbed situations and positioning movements.

The project group recommends continued research as outlined above. A project plan for such a research project will be written based on the findings in the pre-study.

6 References

BIS. (2018, October). *Baninformationssystem.*

Gustafsson, A. (2018, June 7). Maintenance spendings (telephone interview).

Hilary, W., & Smith, R. (2014). Network Optimisation. EiM working group.

Kaya, I. C. (2018, november). *Literature review - A survey of train routing problems*. Linköping university - working paper.

Trafikverket - webpage. (2018, October). *Trafikverket, Bandata*. Retrieved from https://www.trafikverket.se/resa-och-trafik/jarnvag/Sveriges-jarnvagsnat/Bandata/

TrV ASEK. (2018, June). *Schablonmodell samhällsekonomisk beräkning*. Retrieved from https://www.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Planerings--och-analysmetoder/Samhallsekonomisk-analys-och-trafikanalys/schablonmodeller-for-oversiktlig-samhallsekonomisk-berakning/

Weeda, V. A., & Hofstra, K. S. (2008). Performance Analysis: Improving the Dutch Railway Service. *CompRail XI. 103*. WIT Transactions on The Built Environment.

Verstegen, C. (2014). Increasing capacity, improving performance and reducing cost, by reducing complexity. EiM meeting: ProRail.

Version history

Version	**Date**	**Responsible**	**Description**
0	2018-11-11	T. Lidén	First version. For review.
1	2018-12-07	T. Lidén	Revised after review 30/11: Corrected statistics; Including all delay causing failures; More on traffic benefit; Softer conclusion.
2	2018-12-18	T. Lidén	Revised after review 18/12: Including ¼ in Figure 1; Clarifications (operative delays, soft removal, switch turns); Language corrections.
3	2019-01-23	T. Lidén	Small adjustment (overtaking situation at Katrineholm). Cleared all change markers. Final version.