Implementation of New Timetable Rules for Increased Robustness – Case Study from the Swedish Southern Mainline

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Abstract

Due to high demand and high capacity consumption, railway timetables often become sensitive for disturbances and there is little time in the timetables for delay recovery. To maintain a high quality in railway traffic it is important that the timetables are robust and there is a need for strategies and rules for how to make them robust without consuming too much capacity. In this paper we present how timetable rules can be implemented to create more robust timetables. The rules are separated into two categories, rules to make the timetable feasible and rules to increase the delay resistance and recovery. The implementation is illustrated in a real-world case from when the timetable for the Swedish Southern mainline was created for 2019. In the paper we describe how new rules can be applied manually and we discuss advantages and disadvantages by using this approach. We also describe how the rules effect the trains, their timetable slots and runtimes. The results from this study show some of the difficulties when moving from theory to practice and what can be done with limited resources in reality. It gives insights to the practical approach of train timetabling problem which can be used to improve optimization models.

Keywords

Railway timetabling, Robustness, Timetable rules, Implementation, Case study

1 Introduction

The demand for railway capacity has over the years increased a lot. In the densest hours it is not unusual that the demand for train slots is higher than the infrastructure admits. Also, there are often several train operators with different needs, running at the same infrastructure at the same time, that need to be scheduled together. Hence, to solve the puzzle it is tempting to use all possible line capacity for trains and neglect time needed for supplements and margins since it also consumes capacity. The timetable then becomes sensitive for disturbances and there is little time for delay recovery. To maintain a high quality in railway traffic it is important that the timetables are robust and there is a need for strategies and rules for how to make them robust without consuming too much capacity.

In Andersson et al. (2013, 2015) the concept of critical points and the related measure Robustness in Critical Points (RCP) are presented. Andersson et al. (2015) illustrate how RCP can be used in a MILP (Mixed Integer Linear Programing) model to improve the overall robustness in a timetable. However, in Solinen et al. (2017) a comprehensive evaluation of a timetable produced by the MILP model is presented, which illustrates that there are some complications when using the produced timetable in a microscopic environment. There are several simplifications and assumptions made in the MILP model which makes it hard to use straight away and the evaluation shows not only positive results.

The outline of this paper is that the delay problem, with focus on the Swedish Southern mainline, is described in Section 2. In Section 3 the general timetable rules used in Sweden are presented and also the new approach to increase timetable robustness by increasing RCP. In Section 4 the new timetable rules, used for the Swedish Southern mainline 2019, are introduced and we present how the concept of critical points can be combined with other timetable rules and implemented manually in the timetable construction phase. We also describe how the new rules effect the trains, their timetable slots and runtimes, as well as preliminary punctuality effects. In Section 5 we have a concluding discussing on the results where we discuss the advantages and disadvantages by using this approach.

2 Problem Description

Today there are timetable rules for how much time supplements that have to be added to the trains' runtimes, rules for minimum headway times and for some parts of the line, rules for maximum number of train slots per hour, Trafikverket (2016a). These rules are applied most of the time but there are some deviations. Also the timetable tool used by the timetable planners has some shortcomings. For example, the runtimes are only calculated to the centre of the main track for each station and if a train is planned to run on a side track through low-speed switches, the extra runtime needed is missing in the timetable. Until we have a timetabling tool that can identify conflicts and calculate more accurate runtimes there is a need for timetable rules that ensure the feasibility.

To demonstrate the need for new timetable rules a case study from the Swedish Southern mainline is chosen. This is one of the most congested double track lines in Sweden where fast long-distance trains, regional trains, commuter trains and freight trains are using the same infrastructure. The almost 50 km long line goes from Katrineholm, south of Stockholm, to Malmö and further on to Copenhagen in the south, see Figure 1.

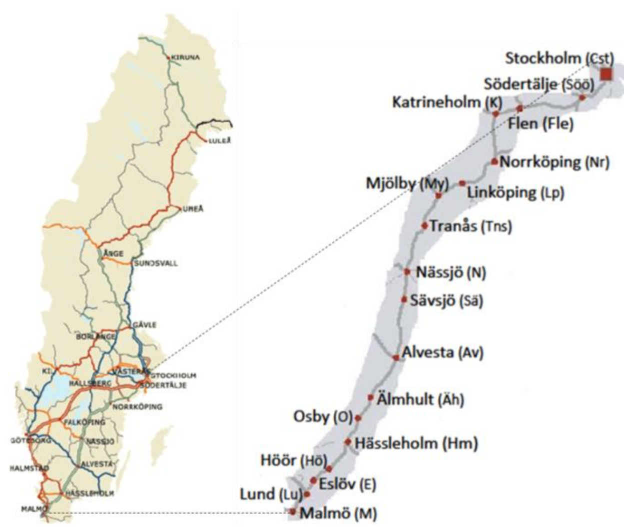

Figure 1. Swedish Southern mainline and the main stations along the line

There is a dense commuter train area between Norrköping–Mjölby and between Hässleholm–Malmö. Over the years, the traffic demand has increased and in the same time the quality of the infrastructure has decreased. This has led to several speed restrictions and maintenance works appearing at the same time, along with a timetable where the trains are scheduled tight, with few margins, to fit them all together. The consequence of this is that the trains operating on the Southern mainline often experience disturbances, they get delayed and have a poor punctuality.

Some trains that are running on parts of the line, such as commuter trains and regional trains, have an acceptable punctuality but long-distance trains that run all the way between Stockholm and Malmö have larger problems. They easily get delayed and since they are running for a long time they often end up disturbing other trains along their way. To get an overall good punctuality in the system, every traffic structure should contribute with the needed robustness and flexibility and we hope to achieve this with new timetable rules.

Several trains get large unexpected delays, over 15-20 minutes, at a short period of time and it is not possible to create a timetable in which these trains can recover from their delays. It would consume too much of the line capacity. Timetable rules to increase robustness should instead be focused on small to medium large delays and increase the possibility for trains with delays around 5-15 minutes to recover from them so these trains can arrive punctual to the end station (i.e. with a delay of 5 minutes at most). A major reason for the medium large delays is that there are a lot of maintenance works and other speed restrictions on the line, to which the timetable is not adapted. If it is not possible to adapt the timetable for all infrastructure variations it is important that the timetable includes enough recovery time so that the delays do not spread too much.

A general finding when studying the timetable and delay statistics is that fast long-distance trains have too short planned dwell times at some stations. In practice, the stops take longer time than the planned 1-2 minutes, which means that time supplement needed for unplanned disturbances in a systematic way will be used for recovering from too long stops instead. This is not a modelling issue but more of a practical problem, not unique for the Southern mainline, since there are no routines for following up actual dwell times today.

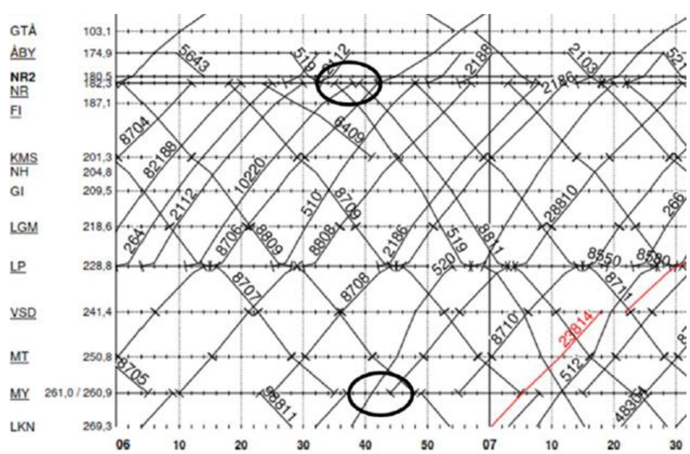

Figure 2. Example of a critical point for southbound trains in Norrköping (NR) with train 519 and 8811 and for northbound trains in Mjölby (MY) with train 520 and 28810.

Another main problem for long-distance trains is that if they get delayed, they often end up after a slower train and have to run with a lower speed for a long time. This increases their delay and also increases the risk for them to delay other trains further on. For example if a southbound fast long-distance train is 5 minutes delayed in Norrköping, it risks to end up after a commuter train and will leave the commuter train area in Mjölby 13 minutes delayed, see train 519 and 8811 in Figure 2. There are several places where this might happen and we refer to them as critical points, which will be described more in section 3.2.

3 Timetable Rules for Creating Feasible and Robust Timetables

When creating a timetable it is important that it is feasible and robust. By a feasible timetable we mean a timetable that is conflict free. It is possible for the trains to run exactly according to the timetable if no unpredicted disturbances occur. By a robust timetable we mean a timetable in which trains are able to keep their originally planned slots despite small disturbances and without causing unrecoverable delays to other trains. A robust timetable should also be able to recover from small delays. Depending on the amount and magnitude of unpredicted disturbances combined with traffic density, the need for robustness differs.

To create a more robust timetable there are two common strategies. The first is to add time supplement to the trains' runtimes. This means that we plan for a longer runtime than it actually takes so that the trains can recover if they get delayed. The downside with this strategy is that it consumes more capacity and that passengers might experience the longer runtime in a negative way. The second strategy is to add headway buffer, which means that we increase the distance between two trains using the same infrastructure. With longer headways, trains do not disturb each other that easily, which prevents delays from spreading. The downside with this strategy is that it consumes line capacity.

3.1 General Timetable Rules used in Sweden

In Trafikverket there are some timetable rules to make the timetables feasible and also to add some time for delay recovery, see Trafikverket (2016a). In this document specific nodes in the railway network are specified together with rules for how much time supplement trains of different categories and speeds should have between these nodes. For example, the nodes on the Southern mainline are Stockholm, Mjölby, Alvesta and Malmö. Passenger trains with a speed above 180 km/h should have a time supplement of 4 minutes between these nodes and passenger trains with a slower speed should have a time supplement of 3 minutes between the same nodes. The timetable planners can place the supplement as they want between the node cities. This strategy was developed nearly 30 years ago and was based on a rough estimation of how much time a train of a certain category needs to recover from typical minor disturbances.

In Trafikverket (2016b) it is specified how closely two trains can be scheduled after each other without causing disturbances, i.e. the minimum headway time between two trains. The headways given in this document is the minimum technical headway rounded up to whole minutes at an aggregated level, resulting in some buffer time between the trains.

3.2 Critical Points

As mentioned before there are points in the timetable that are particularly sensitive to disturbances, referred to as critical points. Critical points appear in a timetable for double track lines where it is planned that a specific train starts its journey after another already operating train, or where a train is planned to overtake another train. In case of a delay in a critical point, the involved trains are likely to require the same infrastructural resource at the same time which might affect the delay propagation significantly. For more theory about critical points we refer to Andersson et al. (2013) and Andersson et al. (2015).

Each critical point is represented by a specific station and a pair of trains, the *leader* and the *follower*, which interact at this geographic location in such a way that a time-dependency occurs, see Figure 3. The follower refers to the train that starts its journey at the critical point behind another train (denoted the leader), or is overtaken in the critical point by the other train, i.e. the leader. The robustness in critical point p is related to the three margin parts L_p, F_p and H_p, and the total robustness for each critical point p, RCP_p, is given by the sum of the parts: $L_p + F_p + H_p$. Below follows a detailed description of the three parts:

- L_p – The available runtime margin time before the critical point for the leader, i.e. the runtime margin for Train 1 between stations A and B in Figure 3. With a large L_p the likelihood of the leader arriving on-time to the critical point increases.
- F_p – The available runtime margin time after the critical point for the follower, i.e. the runtime margin for Train 2 between stations B and C in Figure 3. A large F_p increases the opportunity to delay the follower in favour of the leader, without causing any unrecoverable delay to the follower.
- H_p – The headway margin, or buffer time, between the trains' departure times in the critical point, i.e. the headway margin between Train 1 and Train 2 at station B in Figure 3. In the critical point the trains are separated by the headway margin plus the minimum technical headway. With a large H_p the chance to keep the scheduled train order in the critical point increases, even in a delayed situation.

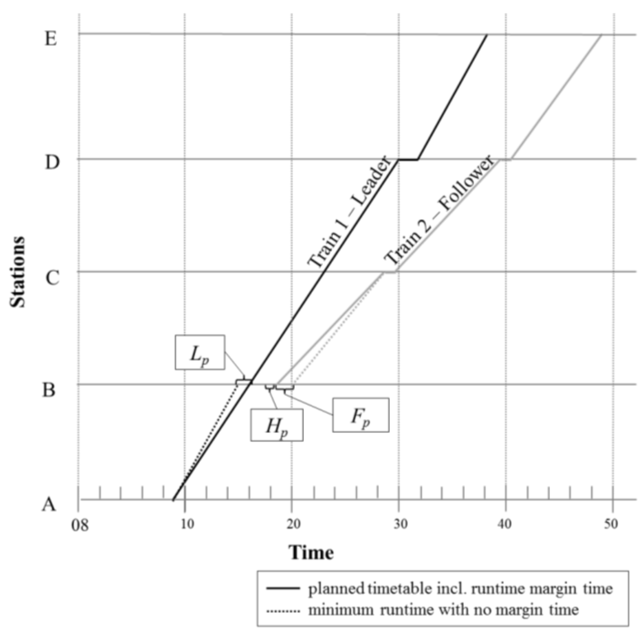

Figure 3: RCP is the sum of the three margin parts: H_p, L_p and F_p.

In Andersson et al. (2015) a MILP (Mixed Integer Linear Programing) model is presented which takes an initial timetable as input, re-allocates the already existing margin time in the timetable to increase RCP and finally returns an improved timetable. The model re-allocates margin time in such a way that the RCP values increase compared to the initial values without increasing the trains' runtimes and the whole timetable gain in robustness. RCP can for example be used in a way to maximize the total RCP for all critical points or as a constraint preventing RCP to be lower than a chosen minimum value.

However, in Solinen et al. (2017) a comprehensive evaluation of a timetable produced by the MILP model is presented, which illustrates that there are some complications when using the produced timetable in a microscopic environment. There are several simplifications and assumptions made in the MILP model which makes it hard to use straight away and the evaluation shows that some trains end up with a lower punctuality even though the overall robustness has improved. This indicates that there are other aspects of timetable planning that needs to be considered in the model as well, so that all trains can benefit from the new timetable, or at least not receive a lower punctuality.

Also, the use of a MILP model requires certain tools and expertise that are not common in current timetabling environments. All of these disadvantages put together makes it hard to use the MILP model in real-world even though the theory behind critical points seems promising.

4 Implementation of RCP and Other Robustness Measures

4.1 New Timetable Planning Rules

To increase the robustness on the Southern mainline new timetable rules has been developed as a complement to the current rules. The rules are separated into two categories, rules to make the timetable feasible and rules to increase delay resistance and recovery.

The rules for feasibility are:

- Time supplement must be added for trains that are planned to use a side track with slow speed switches. A list for all stations and time supplement are included in the new rules as the example in Table 1.
- No planned overtakings on the opposite side of the double track is allowed unless the headway demand in Trafikverket (2016b) is fulfilled also for traffic on the opposite track to prevent trains in the other direction to be disturbed.
- Maintenance works and other speed restrictions that will last for a significant part of the year have to be more carefully planned and sufficient time supplement then has to be calculated and added in the timetable.
- It is not allowed to round off runtimes, time supplements, etc., in a way so that the minimum times are not kept, the maximum deviation is 10 %.

Table 1: Example of how compulsory time supplement for each station is included in the timetable rules. These figures are due for northbound trains that use side track at the stations.

Station ID	Main track nr	Direction of the side track	Time supplement for freight trains (s)	Time supplement for passenger trains (s)
Av	2	North	30	60
Vs	2	North	0	30

The rules for robustness are based on the concept of critical points but with some modifications to make the concept easy to use manually. Not all theoretical critical points are comprised, since they do not always appear in practice. Also, to consider all possible critical points will make it hard to find a feasible timetable unless train slots are removed or significantly modified. Only the most important critical points are selected to be included in the rules and based on real-world circumstances and previous experiences these are critical points where:

- There is a large speed difference between the trains
- The trains interact for a significant amount of time
- There are no overtaking possibility close by
- The points appear in a similar way several times a day
- No freight trains are involved

In the beginning of their run, trains tend to be more on-time than towards the end of their run, which indicates that critical points in the beginning might not need such high RCP values as points in the end. This idea is also discussed in Khoshniyat and Peterson (2017), where the scheduled minimum headway is dependent on the trains' travel times. This idea is not applied for the first version, but it might be an area where the rules can be advanced.

One disadvantage with not using RCP in an optimization model or similar is that it might be complicated for the timetable planners to manually calculate the RCP value for each critical point as they schedule the trains. For that reason each part of RCP, i.e. H_p, L_p and F_p, has been divided into separate timetable rules. Previously, timetable planners have been allowed to place time supplements relatively freely along the line as long as they use the right amount of time supplement between certain nodes as mentioned in Section 3.1. In the new rule the time supplement placement for long-distance trains is more strict and based on the location of critical points. For example, southbound long-distance trains must have the placement of time supplement as presented in Table 2. Here 2 minutes are placed before the most critical points Nr, Av and Hm and 1 minute before the other, not so critical, points. This can be related to L_p in Figure 3.

There is also a new rule to control the minimum headway time at the selected critical points. According to the new rule there must be 6 minutes between the fast and slow southbound passenger trains' departure times in Nr, N, Av and Hm. For northbound trains the limit is also 6 minutes but the locations are instead My, N, Av and Hm. The technical minimum headway time is 2-3 minutes for these stations which then results in a headway margin, H_p, of 3-4 minutes.

Table 2: The placement of time supplements for southbound long-distance trains

Stretch	Time supplement (minutes)
K – Nr	2
Nr – Tns	1
Tns – N	1
N – Av	2
Av – Hm	2
Hm – Lu	1
Lu – M	1

For F_p there is no timetable rule, but there is an operational prioritization rule that states that the follower in a critical point can be delayed up to 3 minutes in favour for the leader.

When combining the three rules this means that there is a total RCP value of around 8 minutes in each critical point. These 8 minutes consist of:

- 1-2 minutes time supplement for the leader before the critical point (L_p)
- 3-4 minutes headway margin time (scheduled headway time - technical minimum time) (H_p)
- 3 minutes for the follower that can be delayed (F_p)

4.2 Timetable Effects of the New Rules

Since the railway market in Sweden is fully deregulated, the timetable is highly dependent on how the different train operators request for train slots every year. The demand for train slots tends to increase and it is a time consuming process for the timetable planners to create a new timetable each year. This means that the timetable will change from year to year to some extent and it is hard to interpret exactly which effects are due to the new rules and which effects are due to changed train slot requests from the operators.

The most obvious difference between the timetable for 2018 (T18) and the timetable for 2019 (T19) is that the runtimes for fast long-distance trains have changed. The average runtime for all trains combined is still around 4 h and 27 min but for southbound trains the runtime has increased by approximate 6 minutes and for northbound trains the runtime has decreased with 5-15 minutes, see Table 3. According to the timetable rules the dwell times at some stations have increased in T19 but the total amount of dwell time is kept almost the same since the operator has chosen to remove one stop for each train. Instead of making 8 stops in T18 most trains only stop 7 times in T19.

The main reason for the changes in total runtime is that a lot of extra time that is needed to fit all trains together in the timetable has to be added or removed compared to previous year. Depending on how the train slots are requested by the operators, it might be necessary to add extra time for one train to make room for another. The amount of time needed differs from year to year. For example, between Malmö and Lund the traffic is very dense which has led to northbound long-distance trains in T18 having a longer stop in Lund than necessary (6 minutes instead of the needed 2). In T19 most of this extra dwell time is not needed which decreases the total runtime. Instead southbound long-distance trains have to have a longer stop in Lund which increases the total runtime with 2-3 minutes.

Table 3: Timetable change (in minutes) from T18 to 19 for some representative long-distance trains. Trains with odd train ID are southbound and trains with even train ID are northbound.

			Time supplements			
Train ID	**Total travel time**	**Total dwell time**	**Maintenance work**	**Timetable synchronization**	**Delay recovery**	**Rounding**
519	+6	+1	-2,4	+5,0	+1,4	+1,5
525	+6	0	-2,4	+8,0	+0,2	+2,5
537	+6	+1	-2,4	+8,5	-0,3	+0,8
522	-11	+1	-0,5	-4,0	+0,7	-3,5
530	-9	+1	-0,5	-1,5	+1,0	-3,7
540	-6	+1	-2,5	-2,4	+1,5	-2,0

If we compare the amount of time supplement needed for timetable synchronisation in Table 3, we can clearly see that southbound trains have an increased amount of time supplement and northbound trains have a decreased amount of time supplement.

In Table 3 we can see that the amount of time supplements differs a lot between T18 and T19 and also between individual trains. For example, in T19 there is less time added to handle maintenance works, but the time added for delay recovery has increased some. However, the main reasons for the change in total travel time are the time supplements not related to delay recovery.

Also other trains in the timetable have been affected by the new timetable rules, some trains that are using side tracks have been given longer runtimes if it is necessary according to Table 1 and some trains have been moved backwards or forwards so that the minimum headway time of 6 minutes is fulfilled. Some of the most affected trains are the extra rush hour commuter trains that run between Norrköping and Mjölby at 6:00-8:30 a.m. and 15:00-18:30 p.m. The main structure is that there are commuter trains running in a periodic 30-min timetable and the operator wants the extra trains to build a periodic 15-min timetable during rush hours. However, due to the amount of traffic, the rule of 6 minute headway in the critical points combined with the trains' different speed and stopping pattern makes this hard to achieve. Sometimes the commuter trains run with 14/16 minute distance, sometimes with 10/20 minute distance and in one occasion the intermediate time is 5/25 minute.

In the southern commuter train area the timetable planners have chosen to deviate from the 6 minute headway rule since the leader has a long dwell time planned before the critical point. This extra dwell time can be seen as margin time of type L_p in Figure 3. The total RCP value stays the same which makes this shift from a longer H_p to a longer L_p acceptable. The deviation from the 6 minute headway makes it easier to combine all train slots and we can avoid to add too much time supplement and increase the runtimes.

For most trains it is possible to follow all timetable rules, but in some rare situations the timetable planners had to deviate slightly from either the node placement or the 6 minute headway to be able to create the timetable.

4.3 Preliminary Punctuality Effects of the New Rules

The timetable with the implemented new timetable rules, T19, was applied the 11th of December 2018, which means that there is not much time to gather statistics. The following reasoning is based on only one month of statistics and can simply give a preliminary indication of the result. The statistics are gathered from all normal weekdays from the same winter period in T18 and T19. All trains with a large disturbance of 15-20 minutes or more are excluded from the results and a train is considered punctual if it is at most 5 minutes delayed at the end station.

When studying fast long-distance trains there is a clear improvement from T18 to T19. Southbound trains, that had the worst punctuality in T18, have an increased punctuality from 74% to 90%. Northbound fast long-distance trains had a better punctuality from the beginning but their punctuality has also improved from 87% to 93 %. The punctuality for regional passenger trains has not changed that much, in the north part of the Southern mainline it has improved slightly and in the south part it is around 96% in both T18 and T19. The punctuality for freight trains has improved around 8 percentage points from T18 to T19 and one reason could be that the other trains are more punctual due to the new rules and do not disturb the freight trains that frequently.

Commuter trains between Norrköping and Mjölby have received a higher punctuality since the risk of being delayed due to an already delayed long-distance train has decreased with the new timetable rules. The punctuality for commuter trains is measured as a delay of maximum 3 minutes (instead of 5 minutes) and the punctuality has increased from 95% to 97%. For commuter trains in the south of Sweden the timetable has not change that much and the punctuality has decreased with some percentage points due to other reasons than the timetable design.

5 Concluding Discussion

In this paper the use of new timetable rules and their effect on the timetable and punctuality are analysed. The main focus is to study how the robustness measure RCP can be used manually to increase the timetable robustness as a short term solution, until we have a software or optimization model to support the timetable planners. The results show some of the difficulties when moving from theory to practice and what can be done with limited resources in reality. If there is no practical possibility to use an optimization model to increase RCP, the timetable planners have to do it manually when they create the timetable. It soon becomes hard to grasp all consequences of adjusting train paths and it is also hard to know which solution is the most just for all operators. In the presented case study, some fast long-distance trains got longer runtimes and some commuter trains did not get their desired periodic timetable. For an experienced timetable planner this might be hard to overview but it is even harder to find suitable constraints in an optimization model that can handle all aspects and all eventualities in a way that would not distort competition. With a manual approach it is easier to consider the experience of the timetable planners, they have gain knowledge from previous timetables and sometimes know intuitively what is possible to achieve and what is not.

One other finding is that it is not possible to have hard rules for all situations, it is necessary to make deviations from time to time, not to end up with unacceptable consequences for the trains. This is one reason why it is hard to use robustness rules as unbreakable constraints in an optimization model.

The manual implementation shows that there are still some difficulties that need to be solved before RCP and other robustness measures can be applied in a timetable optimization model. However, the preliminary punctuality results indicates that the concept of critical points and RCP can be useful also in a manual way to improve the punctuality. We can for example see a large improvement for southbound long-distance trains who have suffered from a poor punctuality for years.

To support the timetable planners the presented robustness measures could be implemented in a software tool, helping them to get a better overview of the robustness and how their decisions affect the robustness. The future plan at Trafikverket is to, in a few years, start to use a software tool including more microscopic data when creating timetables. This will result in a higher degree of feasibility and the need for timetable rules concerning feasibility decreases. In this future software it could be possible to also include the RCP calculation and the presented robustness rules. To illustrate the robustness with the presented rules in a software tool can be seen as a step towards automatic timetable construction and the results from this study can be used as an input to which rules that need to be implemented.

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