Timetable Rules and Strategies for Double Track Maintenance Work

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Abstract
When large maintenance work is done at a double track line, it is often possible to have one of the two tracks open for traffic. The traffic then run with single track operation which heavily affects the capacity and need to be planned in an early stage, before the yearly timetable is finalized. Today, in Sweden, there are some difficulties when planning for maintenance works and how to adapt the reduced capacity in the timetable. Due to an increased demand for capacity and for better punctuality from train operators, there is a need for more well thought-out strategies for how to handle the capacity restriction and for how much robustness is needed in the timetable to preserve a certain quality.

In this paper, we present a study which assess strategies for double track maintenance work leading to single track operations. A simulation study is performed in which three different timetable strategies are tested and evaluated. The aim is to find strategies and timetable rules to better handle capacity reductions at double track lines so that trains can run with high quality even though there are maintenance works at the same time. In the paper we discuss the advantages and disadvantages with the three strategies and how they affect train slots, runtimes and punctuality.

Keywords
Railway timetabling, Robustness, Capacity reduction, Simulation, Punctuality

1 Introduction

The railway infrastructure is from time to time in need of an upgrade. For example, the tracks or the contact line need to be replaced to prevent it from break down and cause larger disruptions. When large maintenance work is done at a single track line, no traffic can use the line during the work. For a double track line it might be possible to still have one of the two tracks open for traffic. The traffic is then run with single track operation which heavily affects the capacity and need to be planned in an early stage, before the yearly timetable is finalized. Lidén (2015) presents a survey of problems and conducted research in the area of railway maintenance planning in which several problem areas are discussed. In previous research, e.g. Vansteenwegen et al. (2016) and Van Aken et al. (2017) models and algorithms are proposed to re-schedule trains in case of planned maintenance works.

However, the models tend to include complicated calculations and do not always include the robustness aspect. Until there is a complex system support to guide the timetable planners, there is a need for more well thought-out timetable strategies and suggestions of suitable headways and time supplements to preserve a certain quality.

Today, in Sweden, there are some practical difficulties when planning for maintenance works and how to adapt the reduced capacity in the timetable. There are no general guidelines for single track operations due to maintenance works in the official timetable rules presented in Trafikverket (2016). The Swedish implementation of the timetable planning tool Trainplan (Trapeze, 2019) used by Trafikverket does not support different infrastructure variants and most of the capacity restrictions have to be adapted manually. How much time supplement that is needed to handle single track operations is estimated by timetable planners and effects on headway times due to the signal system layout is often ignored. Traditionally, temporary single track operations have been handled with reduction of train paths and one single time supplement for trains passing the work section. This approach has shown to result in poor punctuality and due to an increased demand for capacity and for better punctuality from train operators, the capacity restriction and robustness needs to be studied further.

In this paper we present a study which assess strategies for double track maintenance work leading to single track operations. The aim with the study is to give better knowledge to Trafikverket in deciding how to maintain punctuality during maintenance work. We want to find strategies and timetable rules to better handle capacity reductions at double track lines so that trains can run with high quality even though there are maintenance works at the same time.

The outline of the paper is that in Section 2 the three most used timetable strategies are described together with the observed punctuality effect of today's timetable construction. Section 3 contains general rules that originates from the observations of previous timetable constructions. These rules has been developed in this study since we discovered that today's construction often resulted in infeasible timetables in practice. Section 4 describes the simulations study in which the three timetable strategies are evaluated with disturbances. Also how much time supplement is needed for each strategy to maintain punctuality is evaluated. In Section 5 we have a concluding discussion on the result of the simulation study and also on the advantages and disadvantages of the different timetable strategies.

2 Timetable Strategies for Handling Temporary Single Track Operations

Different timetable strategies have been used in Sweden to handle single track operations. The strategies can basically be grouped in to three different approaches; full re-scheduling, trains scheduled in groups and only time supplements. At first we analyse some single track operations and how they have been handled in the timetable are studied. Then the three strategies are described more in detail.

2.1 Effects of Todays' Timetable Construction

The studied examples are real-world examples where timetable planners have modified the timetables fully with respect to the temporary single track operation. These timetables showed that the planners had squeezed in as much trains as possible over the single track sections without violating the theoretical feasibility. This lead to the timetables becoming very sensitive for delays and the trains easily disturbed each other. In some cases even smaller disturbances would affect the operations for hours after they had occurred due to lack of recovery time in the timetable. Another common method used by the timetable planners was to add a few minutes extra time supplement at the track sections just before the station where the single track operation started. The reason for this was to get the train to arrive to the single track section in exactly the right time, when a train in opposite direction left the single track. This extra time supplement did not add any real value to the timetable, it was just a way of puzzle the trains together. In fact, the time supplement instead often led to trains arriving too early to the already occupied single track section, causing even more disorder.

The study of the real-world timetables indicates that there is a need for restrictive timetable rules to prevent timetable planners to construct too optimistic timetables. In purpose of finding good timetable rules and to analyse how much additional time supplement needed to maintain a high quality, a simulation study is performed where three different strategies are evaluated.

2.2 Three Timetable Strategies for Evaluation

The three chosen strategies are common strategies for handling single track operations. All strategies have to some extent been used previously for planning single track operations, but in general, the result shows poor punctuality regardless of strategy. The three strategies are:

1) *Full re-scheduling of all trains to make a feasible timetable including the single track operation*

   With full re-scheduling of all trains every single track section needs to be planned with a separate timetable. For larger maintenance works that moves along the line this can give up to 10 different timetables over a year. This strategy requires a lot of planning resources but will give the dispatchers a conflict free timetable for every stage of the maintenance work.

2) *Trains scheduled in groups running in the same direction over a longer part of the line including the temporary single track*

   To avoid many timetable variants trains can be arranged in groups before the single track operation begins. First, a group of trains run in one direction and doesn't meet other trains until the whole group has passed the chosen section. Then a group of trains running in the other direction can pass the section. This strategy can be used to maximize capacity utilization and also to construct a timetable that covers more than one track section without scheduled meetings between single trains. This reduces the number of timetable variants needed when the maintenance work moves along the line.

3) *No re-scheduling other than adding time supplements for the trains passing the single track section*

   With no re-scheduling the only modification done is adding time supplements in the timetable. The trains can be in conflict in the timetable and it is up to the train dispatcher to solve them as they happen. This strategy requires only one timetable variant but it increases the amount of work for the train dispatchers.

3 General Rules

Due to previous experiences with poor punctuality regardless of strategy used, a set of general rules was developed even before the evaluating simulations. Real-world examples of timetables with temporary single track operations was studied and it was clear that characteristics of the signal system and driver behaviour often were ignored which made most of the timetables only theoretically feasible. Each area that generates need for extra timetable rules is presented below.

3.1 Time Supplements for Reduced Speed

The timetable planning tool used by Trafikverket does not support different infrastructure variants. This means that the reduced speed for trains passing a maintenance work has to be added manually as time supplement. The time supplements need to be calculated separately for each train category and then added for each train.

3.2 Construction with Start/Stop Supplements

A common method used in the studied timetables was to add a few minutes extra time supplement in the track sections just before the station where the single track operation started. The reason for this is to get the train to arrive to the single track section in exactly the right time, when a train in opposite direction left the single track. However, train drivers are not always aware of this time supplement. To adapt their speed to the planned timetable the train drivers have to use their experience of how long time this track sections usually takes to drive in full speed. In the majority of the cases, train drivers do not notice the deviation, run with full speed towards the single track section and ends up stopping before the entry signal. Since it takes more time for a train to accelerate from zero, than if it was running with a reduced speed, the planned runtime on the single track section is not enough and the train gets delayed. See how the delays are spreading in Figure 1.

This combination of timetabling and driver behaviour create a chain reaction that will last until there is a gap in the timetable wide enough that trains leaving the single track section do not affect trains entering this section.

To avoid this situation, time supplement should not be added on the last section before the temporary single track. Trains should instead, if necessary, have a planned scheduled stop at the border station of the single track. With this planned stop the timetable planning tool will automatically calculate the run time needed, included the extra time for acceleration from zero.

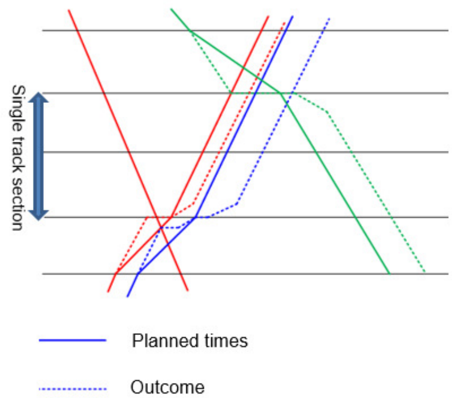

Figure 1: Illustration of how delays are spreading when trains have time supplement added before the single track section. Instead of slowing down they run with full speed and have to stop before the section.

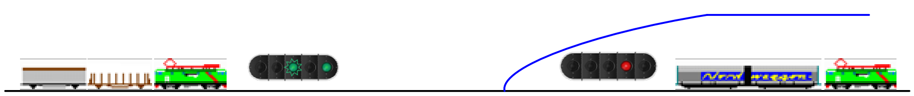

Figure 2: The train to the right has started to accelerate (blue curve) and the following train to the left get the signal aspect “expect stop” in the next signal.

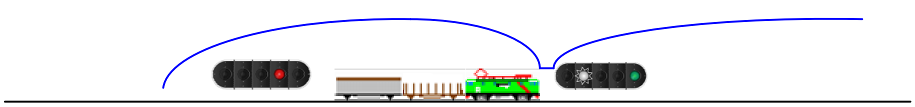

Figure 3: The first train has left the block section which makes the signal green, but the following train gets no update of the signal aspect and has to slow down to surveillance speed (blue curve).

3.3 Headway on the Single Track Section

All Swedish double track lines have full signalling in both directions, headways are not restricted by a reduced number of block signals even if trains run on the opposite track.
The automatic train control (ATC) system in Sweden gives the possible headway between trains (the distance between two trains following each other on the same infrastructure). The ATC system transfers signal information on certain points through balises. Balises are always present at the location of signals, but they can also be present before the signals to

transfer signal information from the next main signal. Contact with such repeating balise will then update the on-board computer with a new signal aspect. On smaller stations repeating balises are not common since these stations are primary used for maintenance works and operational train dispatching and not for everyday traffic. This will influence the headway if more than one train have to stop before entering the section with single track operation. When two or more trains have to queue up to wait for an oncoming train to leave the single track section the second train will start with signal aspect "expect stop" in the next signal, see Figure 2. Since there are few repeating balises, the change in signal aspect can´t be communicated to the ATC system between the signals. The train will therefore not get information on an update in the signal aspect, which will force the train to slow down to the surveillance speed of the block section before passing the next signal, see Figure 3.

This characteristics of ATC makes it impossible to maintain the standard headway used for trains on this line. The general rule is therefore that one minute must be added to the standard headway used for normal train operation.

3.4 Time Between Trains on Border Stations

In the studied timetables with single track operations many trains had the same timetable time for entering the single track section as oncoming trains had when leaving the section. This means that there is no margin time between the trains for the switch to change position and for the signal system to reverse block direction. To have enough time for such necessary actions at least one minute must be planned between trains in different direction leaving and entering the single track section.

4 Simulation Study

In purpose of finding good timetable rules and to analyse how much additional time supplement needed to maintain a high quality, a simulation study is performed. We use the microsimulation tool RailSys, (RMCon, 2019) commonly used in both industry and research to perform simulation studies. In the study a sequence of simulations was done to analyse the three different strategies to handle single track operation. Also a reference simulation with both tracks in operation is used to establish a comparable punctuality with normal everyday delays caused by other circumstances than the single track operation. The needed additional time supplement is calculated by comparing the results with the results from the reference simulation. When same punctuality is achieved at commercial stops surrounding the single track section, the amount of needed time supplement is defined.

The chosen line for the simulations is the Swedish Southern mainline, a double track line with dense traffic consisting of fast long-distance trains, regional trains, commuter trains as well as freight trains. The location for the single track section is between Tunneby and Osby (see Figure 4 for a cut-out from the actual timetable) but the whole simulation area is from Katrineholm, south of Stockholm, to Malmö.

To analyse how the length of the single track section affects the strategies, three different lengths are tested for each of the strategies. To make the studies more general, runtime is chosen to define the length instead of kilometres. Single track sections that takes 5, 10 and 15 minutes for fast trains to pass are used in the simulation. In the scenarios the maximum speed for the trains is restricted to achieve the right passing time. Also, the general rules stated in section 3 are used for the strategies they can be applied.

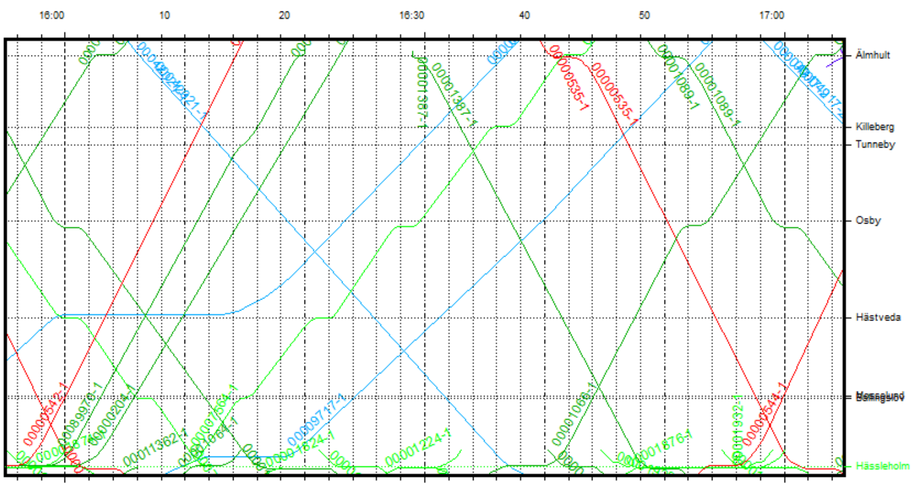

Figure 4: Peak hour traffic between Älmhult and Hässleholm, Red lines represent fast long-distance trains, dark green lines are intercity and fast regional trains, light green lines are commuter trains and blue lines are freight trains.

In the simulation, trains are disturbed with stochastic disturbances. These disturbances are inserted as entry delays, dwell time delays and line delays. Entry delays are taken from empirical delay data for the different train categories at the station where they enter the simulation area. Dwell time delays are based on empirical data from The Royal Institute of Technology (KTH) in Stockholm and inserted at each station where trains have a planned stop. The data is grouped in to different categories depending on number of passengers using the station. These delays represents the dwell time uncertainty, for example longer passenger exchange time due to train door failure. The third category of delays is line delays, i.e. delays that appear on the line between stations. These delays represent for example failure of traction units, transmission failure between signal equipment at the tracks and on-board computer that forces trains to run at reduced speed or temporary speed restrictions. These three types of delays are commonly used in Sweden in a way so that the simulations can represent realistic operational traffic in the Swedish network.

4.1 Results of the Three Strategies

After simulation of all strategies for all three scenarios with different single track length, it is possible to attain some results to evaluate. In all simulations, additional time supplement is necessary to maintain the punctuality. Depending on strategy and length of the single track section, the needed amount of time supplement differ. The supplement is needed to handle the fact that trains are not running on time. They do not always arrive to the single track section on time and need time supplement after the single track section to recover from this delay that might have increased due to the single track operation. If the time supplement is placed on the single track section instead of after, capacity would decrease.

In the following sections the summarized results of the three strategies are presented one by one.

1) Full re-scheduling

With this strategy all timetables have to be conflict free and fully adapted to the single track operation. Therefore, much effort needs to be put into creating the new timetables.

In the scenarios with 10 and 15 minutes of running time over the single track section, there is not room for all trains in the original timetable and traffic must therefore be reduced.

In all three scenarios an additional time supplement is needed to maintain punctuality for long distance and regional passenger trains. The amount of supplement is 50 % of the runtime over the single track section, e.g. if it takes 10 minutes for the trains to pass the single track section, the needed time supplement is 5 minutes. For local passenger trains and freight trains additional time supplements is not needed until the single track section takes more than 10 minute to pass. For local passenger trains the reason for this is that they have a much higher punctuality when arriving to the single track section than other trains and therefore often get prioritized. Freight trains have a lot of time supplements already in the original timetable for overtakings etc., and therefore they have less need for additional time supplements. For local passenger trains and freight trains an additional time supplement of 5 minutes is needed if the single track section takes longer than 10 minutes to pass.

2) Trains scheduled in groups

This strategy is only simulated for the scenarios with 10 and 15 minutes travel time over the single track section. The reason for this is that there is no need to group the trains together in the 5 minutes scenario. In the other two strategies all trains could fit in the timetable with acceptable amount of time supplements. If they were to be grouped we would deviate even more from the original timetable, give the trains longer runtimes and not gain anything with it.

In the simulated scenarios a large amount of additional time supplement, particularly for freight trains, is needed to gather the trains into groups. There is also a shortage of tracks near the single track section to store trains to form the groups. Passenger trains have to pass the freight trains before the single track section to be the first trains in each group. Else, they have to run after freight trains and much additional time will be necessary to lower the passenger trains' speeds to match the freight trains'.

The difference in runtimes between passenger and freight trains leads to large heterogeneousness within the train groups. This results in a timetable with a low ability to move the maintenance work to different sections along the line unless the trains are re-grouped once again. If the maintenance work consists of several moving stages a lot of timetable variants is needed in the end. However, the strategy will still reduce the number of needed timetable variants by half, compared to the strategy with full re-scheduling, because the single track section can often be moved at least one short section along the line without re-scheduling the timetable. If the traffic is more homogenous the need for several timetable variants with different train groupings decreases even more.

The simulation results show that the same amount of additional time supplement as for the strategy with full re-scheduling to handle late trains. Long distance and regional passenger trains need an additional time supplement which is 50 % of the runtime over the single track section and local passenger trains and freight trains an additional time supplement of 5 minutes if the single track section takes longer than 10 minutes to pass.

3) No re-scheduling

In this strategy, no re-scheduling of trains is done, only additional time supplements are used to give trains the possibility to recover from the delays caused by the single track operation. In the simulation process it became clear that this strategy shows a much larger need for time supplement than other strategies.

One major issue for the punctuality is trains that systematically have meetings on the single track section every hour. Passenger trains have a more or less periodic timetable in Sweden and in some cases these trains meet at the same time every hour. These trains will frequently cause disturbances and delays for all other trains as well. In such case, all trains will need an additional time supplement which is 200 % of the runtime over the single track section to maintain punctuality. Therefore an additional rule for this strategy was developed; it is not allowed to have systematically meetings on the single track section. Trains that unfortunately have a meeting there in the original timetable have to be removed or moved to another time.

With the new rule forbidding systematically meeting the amount of additional time supplement needed to maintain punctuality is 100 % of the runtime over the single track section. This means that if it takes 10 minutes for a train to pass the single track section, the needed time supplement after the section is 10 minutes.

5 Concluding Discussion

The results from the case study show that it is important not to schedule trains as close as possible when they leave/enter the single track section. There is a need of headway margin time between the trains in opposite direction, not to spread delays too easily. Also there is a need for additional time supplements that can handle the everyday delays combined with the increased disturbance risk of the single track. In all three strategies additional time supplements are needed to handle trains that are arriving delayed to the single track section. However, depending on which strategy used, the amount of time supplement needed differs. In general, as less accurate and not conflict free the timetable is, the more supplements are needed.

Since the strategy with full re-scheduling results in the least time supplements, it would be easy to draw the conclusion that full re-scheduling always is preferred. However, due to the amount of work needed to produce a lot of timetable variants, it might not be a well-chosen use of recourses. Until an advanced timetabling tool with automatic re-scheduling of trains is implemented, the work has to be done manually and that is very time consuming. On lines or at times with homogenous traffic where the trains are running with similar speed, the strategy with grouping of trains would be a more effective strategy. Then the extra time needed to arrange the trains into suitable groups doesn't have to be that large and we can take advantage of the fact that we don't need that many timetable variants. However, in the case study presented in this paper the traffic was too heterogeneous and the strategy would not give any clear benefits compared to full re-scheduling.

If the strategy with no re-scheduling and only additional time supplements is used, we deliberately allow the trains to be delayed during the maintenance work. We therefore have to add large time supplements in the timetable so that the trains can recover from the delays, which leads to a large increase in the trains' travel times. The benefit with this strategy is that the need for several timetable variant is small, even though the single track section is shifting within the maintenance work. As long as the additional time supplement is placed after all possible single track sections, the same timetable can be used for all of them. This, of course, is only possible if we are allowed to let the trains be delayed for a long part of the line, during all stages of the maintenance work. If the time supplement is placed directly after a single track section it might be of no use when the maintenance work moves to the next section of the line.

The result from this study gives knowledge to railway timetable planners for how and when to use different timetable strategies. The amount of additional time supplements needed to preserve punctuality for each strategy is related to the specific case presented here and that case can be seen as a worst case scenario. The traffic demand is high, with a large heterogeneousness combined with a high level of disturbances on the line. If there are less trains or if the trains are running more punctual from the beginning, the need for large additional time supplements decreases. Exactly how much time supplement that is needed for different cases is for future work to analyse, but we can conclude that by using the time supplements suggested in Section 4, the punctuality would be preserved in most cases.

Also, regardless of strategy, it is important to take the characteristics of signal system and driver behaviour into account when adapting a timetable for a single track maintenance work. The general rules presented in Section 3 should always be applied since they concern the practical feasibility regardless of the amount of trains and disturbances. Without the use of the general rules the timetable will not be completely conflict free and the trains cannot run on time even though they are re-scheduled.

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