Highspeed Railway Assessment - Rail Specific Planning and Development Analysis

APPENDIX 4

REPORT

Passing loops

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Abstract

Overtakings are important events on double-track railway lines operated with mixed traffic. The overtakings affect the travel times, the capacity and the risk of delays. Overtakings usually take place on passing loops and this report deals with the design of such loops and how they should be located in relation to each other.

The study is considered to be the first study of this kind of details for a future Norwegian high-speed railway network. It is therefore natural to investigate a couple of typical situations as regards traffic mix, train speed, stopping pattern, infrastructure parameters etc.

Based on the performed analyses within this rather broad evaluation space we are able to recommend the following design and construction rules-of-thumb:

Loop design

- Speed in entrance turnout (diverging track): 130 km/h.
- Length of loop track (between signals): 685 m.
- Speed in exit turnout (diverging track): 100 km/h.

Combined overtaking and passenger stop is a very efficient way to minimize the scheduled delay and reach a high average speed for the overtaken train. For this reason it is preferable locate passing loops at stations where train stop for passenger exchange.

Loop spacing

The analyses show that a double-track railway line operated with 1-2 high-speed trains/h and direction has capacity for regional trains operated at (at least) the same frequency of service **or** 2-4 freight trains/h and direction. To achieve this capacity the following design criteria has to be met:

- 60 km inter-loop distances for lines planned for one high-speed train/h and direction.
- 20-40 km inter-loop distances for lines planned for two high-speed trains/h and direction.
- Special care has to be paid for the exact locations of the loops. This is most important when the high-speed traffic is operated with two trains/h.

Delay analysis

This PM does not address delay propagation and need for additional time supplements to cope with delay propagation in overtaking situations. The reason for this is that these delay relationships are strongly dependent on the details in the infrastructure design as well as the timetable. We believe that it is better to perform such studies at a later stage when more details are known about the operation.

Introduction and background

Operation of double-track lines differs from operation of single-track lines since the crossings may take place anywhere and without crossing time. However, double-track lines may be operated with a mix of trains at different speeds, e.g. high-speed, regional and freight trains. The consequent mix of speeds implies overtakings where faster trains pass slower ones. The overtakings share some features with crossings:

- They increase capacity (for a given traffic mix).
- They have to be carefully planned in the timetable.
- They imply time losses (scheduled delays).
- They mean a risk of delay propagation (knock-on delays).
- They require dispatching actions in disturbed situations.

How these features affect the operational outcome of a railway line depends heavily on the infrastructure design and operational factors such as timetable and occurrence of disturbances.

This report addresses two factors of special interest: the design of passing loops and the spacing of passing loops (inter-loop distance). The aim is to show how different design parameters for the passing loops can be chosen in order to achieve reliable and high-capacity operation and how the loops shall be located in relation to each other to make the required operation possible.

Overtakings – uncertain and time consuming events on double-track lines

Usually an overtaking means that a slower train brakes and stops on a passing loop to let the faster train pass. The procedure most often imply scheduled delay to the slower train and increased risk of delay propagation for both trains.

The passing loops also have a great impact on capacity and timetable flexibility. Two examples are shown in figure 1 and 2. Both timetables show the traffic in one direction on a double-track railway line of about 400 km length. In the first case a 30-minute high-speed traffic is combined with regional traffic with the same frequency of service. The line has only eight passing loops and two of these are used for (scheduled) overtakings. Especially the overtaking at loop 5 seems to cause the regional trains some scheduled delay since they have to wait for the high-speed trains to pass.

Figure 2 shows a somewhat different line design with elven passing loops. This line is operated by a mix of high-speed trains every 30 minutes and freight trains. The timetable shows that the capacity for this traffic mix is two high-speed trains and four freight trains per hour. In the example seven out of eleven passing loops are utilized for (scheduled) overtakings and these cause the freight trains rather much scheduled delay.

Just the scheduled delay is a factor of great importance. It affects not only the run times (travel times), but also capacity and operational robustness. The scheduled delay is therefore a given measure of performance when double-track railway lines are to be designed.

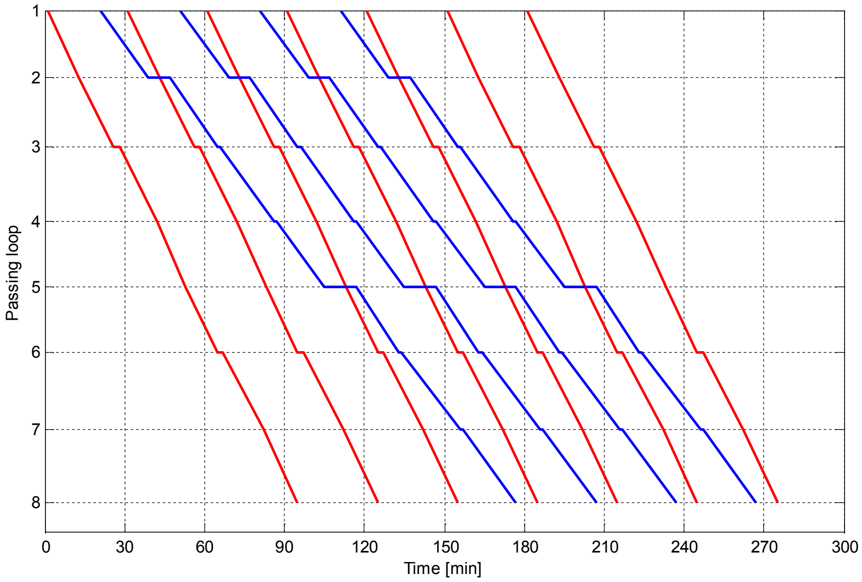


Figure 1Timetable example for a mix of high-speed and regional trains.

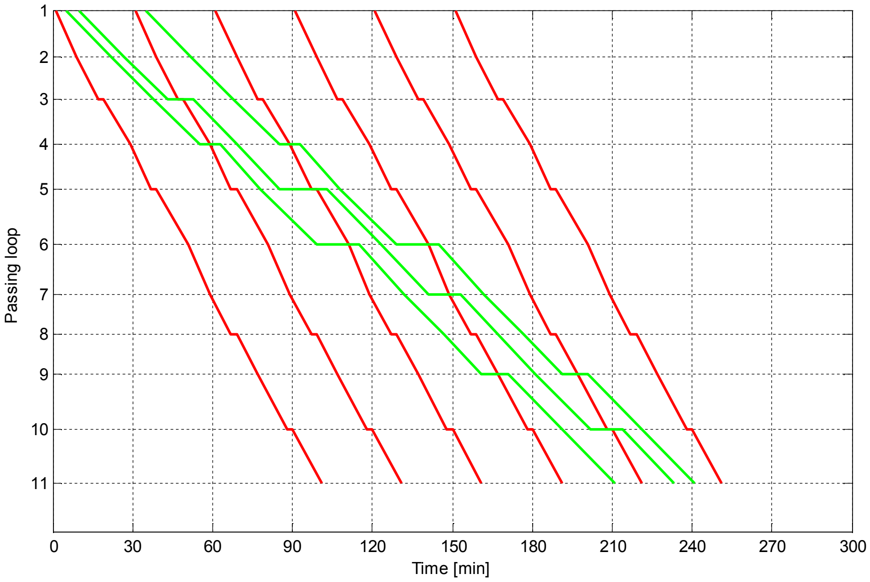


Figure 2 Timetable example for a mix of high-speed and freight trains.

Design of passing loops

The passing loops have to be designed for time efficient overtakings. This means that turnouts and track lengths have to be chosen so that the time needed for the faster train to pass the slower one is as short as possible.

Not only the physical design of the passing loop, but also the interlocking system has to be designed and adjusted to overtaking situations. This adds requirements of short release and setting times for train routes as well as thought locations of release contacts etc.

It is also important to distinguish situations where overtaking is combined with a passenger stop. This means that dwell time as well as time supplements for deceleration and acceleration does not contribute to the scheduled delay caused by the overtaking.

This chapter analyses the effect of some important technical design factors for passing loops on the effectiveness of overtakings. Two different operational situations are addressed; high-speed train overtaking regional and freight train respectively.

The analysis is performed through run time calculations where deceleration and acceleration courses are modelled as well as release and setting times for the train routes. The calculations are pure deterministic and aim at finding the minimum scheduled delay caused to the overtaken train.

The need for deeper studies to find out time supplements needed to prevent knock-on delays will be discussed in the conclusions.

Measure of performance

The scheduled delay for the overtaken train is chosen to be the measure of performance. A scheduled delay is an undesired time added into a timetable due to conflicts with other trains. Scheduled delays are unavoidable on double-track lines with mixed traffic since faster trains catch up with slower ones and these conflicts imply overtakings to be resolved.

Normally an overtaking means that the slower train has to stop at a passing loop to let the faster train pass by. This implies time losses compared to a non-conflicted situation without stop. These time losses consist of time supplement needed for deceleration, dwell time and time supplement caused during the acceleration course.

The scheduled delay does not include time supplement necessary to cope with delay propagation (secondary delays). The need for such supplement has to be analyzed in special order and is not included in this study.

Independent factors

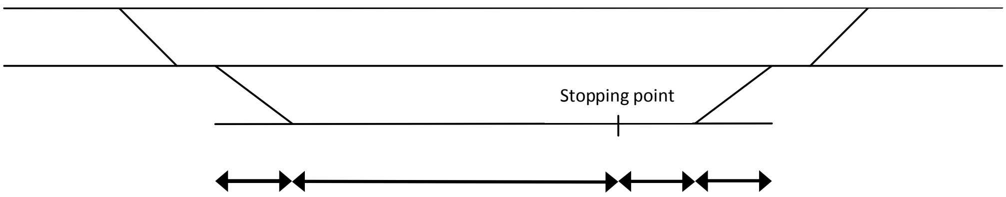
Three independent factors are studied within this assignment:

- Speed restriction at entrance turnouts (diverging track) / length of passing loop.
- Type of overtaking situation.
- Passenger stop during overtaking.

The **speed restriction at the entrance turnout** (diverging track) affects the scheduled delay indirectly. A low speed at the entrance turnout means that the train that is to be overtaken has to perform more of its braking on the main track before the turnout. This in turn means that the faster train has to be scheduled at a greater time distance which gives a less time efficient overtaking.

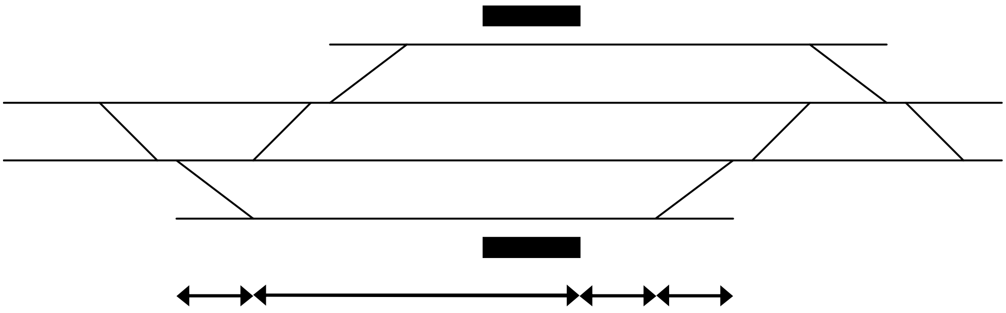
For this reason the speed at the entrance turnout has to be as high as possible. However, a high turnout speed is of no use unless the length of the passing loop is long enough to allow braking from turnout speed down to stop. For this reason it is feasible to link each speed level to the track length necessary for the remaining braking. Three combinations of turnout speed and track length are evaluated: 100 km/h – 310 m, 130 km/h – 585 m and 160 km/h – 900 m. These distances are measured from the tip of the turnout to the stop position (for the first axis) on the loop track and they are adjusted to the deceleration rate of 0.8 m/s^2.

The track lengths on conventional railway lines are usually adjusted to a specific train length, e.g. an extended freight train. The three track lengths tested in this report are long enough to for both passenger trains (200 m) and freight trains (157 m) used, see appendix 1 for details.



Entrance turnout	**Distances [m]**			
100 km/h	160	310	100	160
130 km/h	215	585	"	"
160 km/h	320	900	"	"

Figure 3Alternative loop lengths for an ordinary, one sided, passing loop.



Entrance turnout	**Distances [m]**			
100 km/h	160	310	100	160
130 km/h	215	585	"	"
160 km/h	320	900	"	"

Figure 4Alternative loop lengths for a two-sided passing loop for combined overtaking and passenger stop.

Figure 3 and 4 show two principle designs. The speed level at the entrance turnout determines the distance to the stopping point. A distance of 100 m is assumed between the stopping point and the trap point (the first exit turnout). The exit turnouts have a maximum speed of 100 km/h for the diverging track in all cases. Given the assumed stopping point and acceleration data this speed will not be restrictive for accelerating trains.

Different kinds of **overtaking situations** occur on a double-track line. The fastest train type will normally face overtakings of all slower train types. This means that the high-speed trains will overtake both regional and freight trains. In some cases regional trains overtake freight trains. This combination is not analyzed in this study since we believe that the freight trains that operate a high speed line will have almost the same average speed as a regional train. For this reason only high-speed overtaking regional train and high-speed overtaking freight train is included in this study.

It is feasible to combine an overtaking with a **passenger stop** for the slower (regional) train. Doing so, the time supplements as well as some, or even most, of the dwell time can be regarded as useful time. This helps to minimize the scheduled delay.

Constants

Several factors have been modelled as constants. The most important are:

Vehicle characteristics and maximum speeds. Three train types have been modelled: one high-speed train, one regional train and one freight train. Detailed vehicle characteristics for these trains are shown in appendix 1. The high-speed train is operated by a typical high-speed vehicle (Velaro E) having a maximum speed in this stydy of 300 km/h. The regional train is assumed to have a maximum speed of 200 km/h. The freight train is a light freight train of 564 tons and maximum speed of 140 km/h. All three vehicles have a deceleration of 0.8 m/s^2.

Signalling system. The signalling system is assumed to be ERTMS level 2 (or higher). This means that driving authorisation is continuously updated. The total time needed for release of the entrance train route, set of the passing train route, transmission to the overtaking train and indication to its driver is set to 20 s.

The first block section beyond the station is assumed to be 100 m. This means that the overtaking train has to pass this section before an exit train route can be set for the overtaken train.

Delay situation. No delays are taken into consideration. The aim of the evaluation is just to analyse the minimum scheduled delay needed for an overtaking.

Analysis of alternative designs

Mixing trains with different speeds on the same track means that capacity is lost through different run times. This is seen as “wedges” in the graphical timetable. However, also the overtaking situations, where the slower train has to slow down and let the following, faster train pass, results in capacity losses. These losses mean that the following train has to be scheduled farther behind the slower train which in turn extends the scheduled delay caused by the overtaking.

The time lost in the overtaking situations depends on how fast the slower train can leave the main track. It is therefore of special interest to analyse the deceleration course to see how much extra occupancy time the deceleration phase cause on the main track.

Figure 5 shows the braking curve for a regional train. The braking distance is about 1930 m and the alternative turnout speeds for the diverging track are marked (160, 130 and 100 km/h). The red curve shows how the time supplement increases through the deceleration course. A total stop means that a supplement of 35 s has to be included in the timetable.

This time supplement will cause further capacity loss on the main track until the braking train has reached the loop track. This is marked by arrows in the figure. If the entrance turnout allows 160 km/h the train will pass the turnout tip at this speed and continue through the turnout plus the length of the train before the main track is released by the interlocking system. This is marked by the arrow whose length correspond to a turnout length of 320 m plus a train length of 200 m.

By this time the train will be approximately 700 m from its stopping point and the time lost on the main track could be read from the red curve: 5 s. A lower speed in the entrance turnout gives shorter arrows due to the shorter turnouts, but increased time loss on the main track. In practice this time loss means that the following train has to be scheduled farther behind the slower train, which in turn imply a longer waiting time on the loop track for the overtaken train.

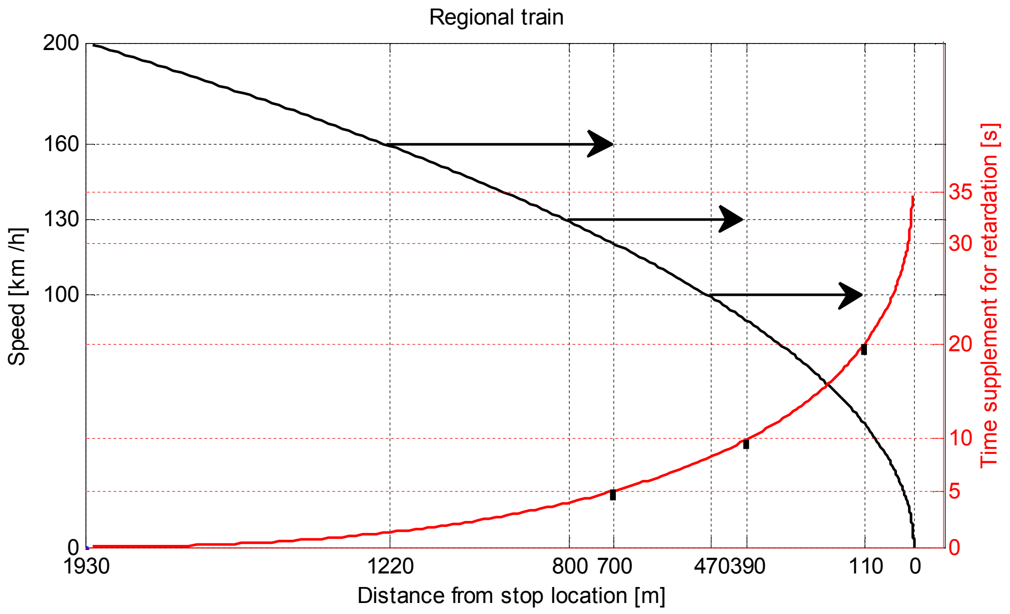


Figure 5 Deceleration curve and time supplement for deceleration for a regional train. Deceleration rate: 0.8 m/s^2.

Figure 5 also shows a “main track time supplement” of 5, 10 and 20 s respectively, for the analysed turnouts. These values will also appear in a graphical timetable for the alternative loop designs, see figure 6.

The timetable shows the three different situations that corresponds to the three analysed loop designs. The left most regional (blue) and high-speed train (red) operates a passing loop with entrance turnout speed 160 km/h and track length 900 m (figure 3 and 4).

The longer extension of the loop gives a farther located stopping position and the lower time supplement needed on the main track makes it possible for the faster train to follow closer on the slower one, compared to cases with a lower turnout speed.

A lower turnout speed means that the loop gets shorter and the stopping position mowes downwards in the figure. A lower turnout speed also imply more time supplement on the main track, which forces the following high-speed train to follow at a longer time distance.

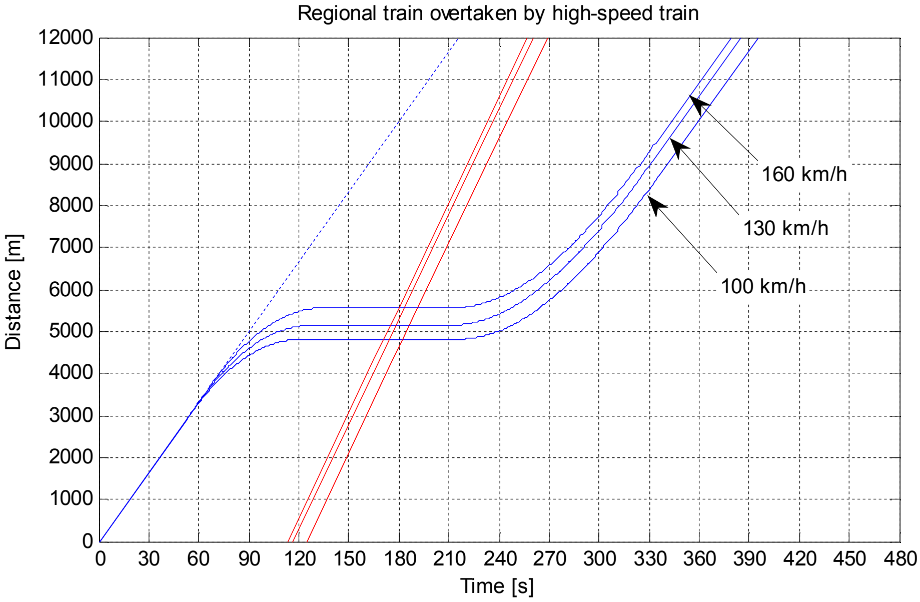


Figure 6 Graphical timetable for overtaking of a regional train on different passing loops. A reference case, without overtaking, is shown with a dashed line.

The time gained from a higher turnout speed is 10-15 seconds for a turnout speed of 130 and 160 km/h respecitively. This corresponds to 6-9 % of the total scheduled delay caused by the overtaking.

The high-speed trains also have to overtake freight trains. This study assumes fast freight trains operated at 140 km/h. This means that turnouts for 160 km/h are over standard. This is also seen in figure 7 as a limited difference between letting the freight train leave the main track at 140 km/h and 130 km/h. The curves are actully the same as for the regional train, since the assumed deceleration rate is assumed to be the same (0.8 m/s^2).

Figure 8 shows the corresponding graphical timetable. It shows clearly that the effect of an increased turnout speed is limited for the freight train. Please note that the higher speed difference between the high-speed and the freight train implies a greater time difference at the start point of the timetable.

The difference between a turnout speed (diverging track) of 100 km/h and 130 km/h is about 10 seconds. This difference corresponds to 6% of the total scheduled delay caused by the overtaking.

The results are summerized in figure 9. Regional trains suffer from greater scheduled delays due to their higher maximum speed (200 km/h) compared to the freight trains.

An efficient way to reduce the impact of the overtaking is to combine it with a passenger stop. This means that deceleration supplement, some of the dwell time and the acceleration supplement become useful (operational) time instead of scheduled delay.

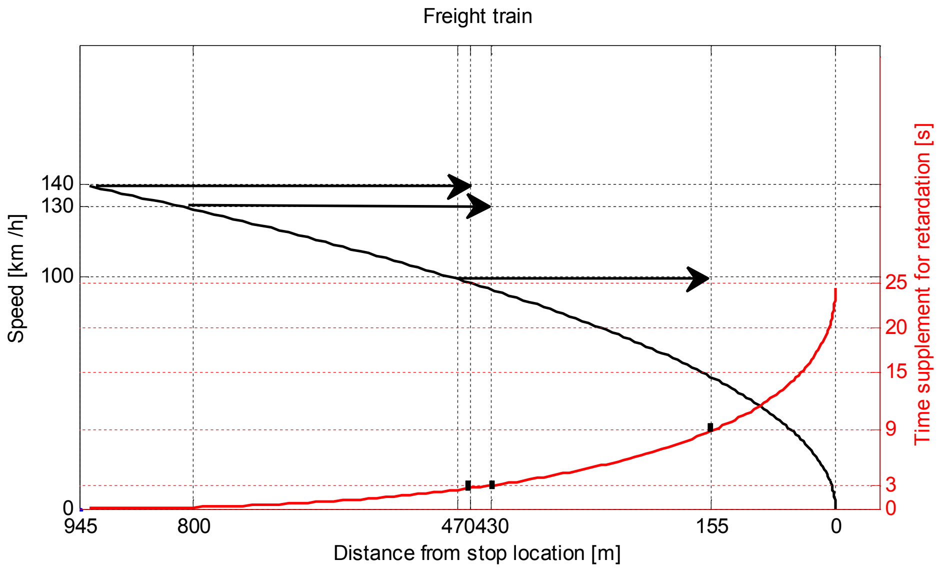


Figure 7 Deceleration curve and time supplement for deceleration for a freight train. Deceleration rate: 0.8 m/s^2.

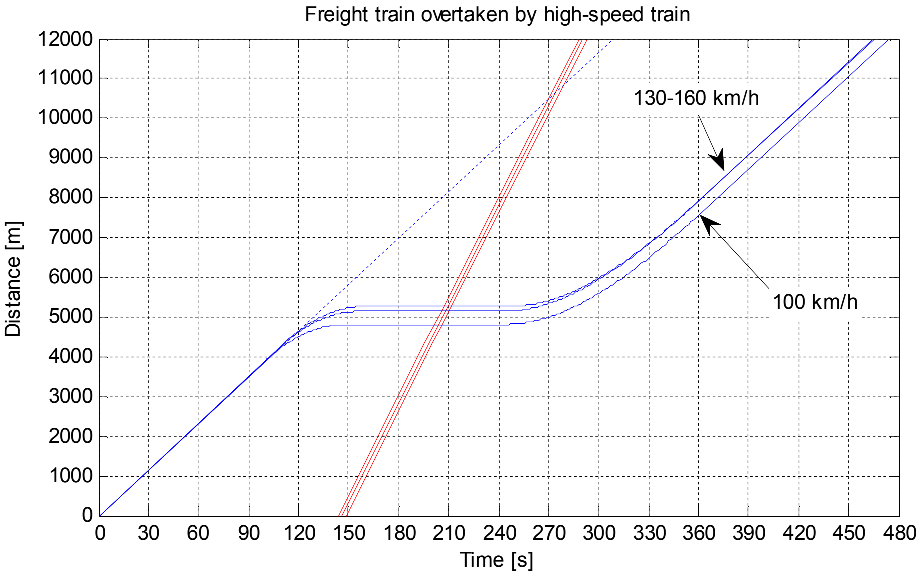


Figure 8 Graphical timetable for overtaking of a freight train on different passing loops. A reference case, without overtaking, is shown with a dashed line.

The dwell time used in figure 9 corresponds to a short regional stop of 60 s and the shown values include time supplements for deceleration and acceleration. For major stations a longer dwell time may be necessary. Those cases mean that an overtaking might be scheduled without scheduled delay.

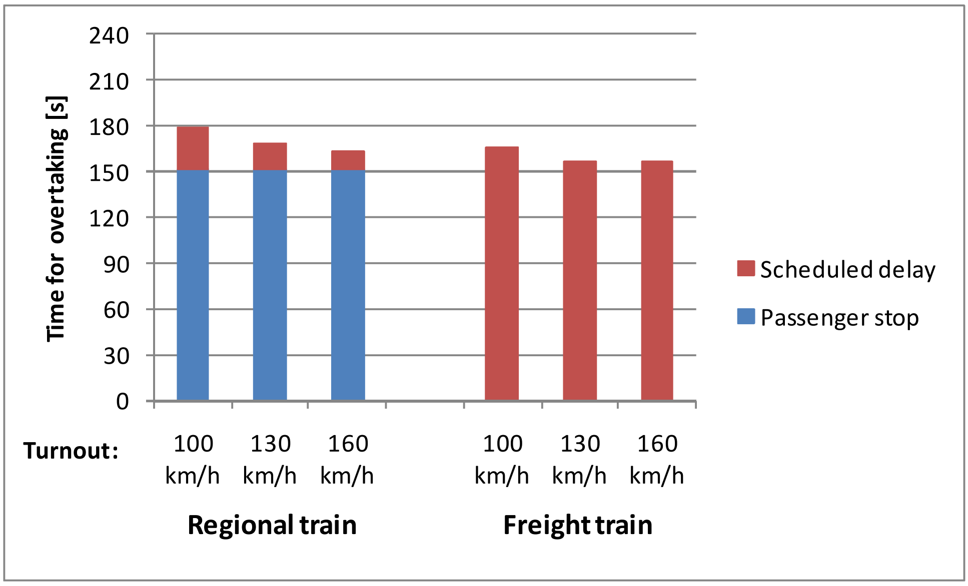


Figure 9 Minimum scheduled delay at overtaking. Regional and freight trains with alternative turnout speeds (diverging track).

It is very important to bear in mind that this analysis only concerns minimum scheduled delay caused by overtaking. Delays in the real operation will cause a need to include also special time supplements to limit the delay propagation.

The amount of such supplements depends on the details in the infrastructure design as well as in the timetable. This means that such supplements must be addressed in special order when more details about the infrastructure and the operation are known.

Loop spacing

The design of passing loops is a question of details where meters of track length and seconds for release and setting of train routes have to be optimised. Another, much more general, factor in the design of double-track lines is the loop spacing (inter-loop distance).

The loop spacing is general since it affects not only the scheduled and knock-on delays, but also the capacity and the number and the structure of feasible timetables. This means that the loop spacing should be analyzed (at least) from two points of view:

- Capacity and operation possibilities, i.e. timetable flexibility, scheduled delays etc.
- Knock-on delays, need for time supplements etc.

The second point corresponds very well to the analyses performed for crossing loops and the same method might be used to estimate the knock-on delays and the time supplements needed for the overtaking. One major difference, however, is that such estimations require detailed knowledge, or assumptions, about the timetable.

It is much easier to foresee a future single-track timetable, since the crossings strongly restrict the timetable variability. A double-track line has much higher timetable flexibility and hence more feasible timetables. For this reason we choose to leave these analyses to a later stage where more timetable details are known.

Even if the detailed delay analyses are left for coming assignments, it is very useful to analyse the capacity effects of different loop spacing strategies. The analysis is performed as a multi-factor analysis where the effect of the inter-loop distance is analysed together with operational factors such as maximum speed of high-speed trains, frequency of service, stopping pattern and traffic mix.

The situation is somewhat more complicated since real inter-loop distances varies along a line. This variability is unavoidable since demographical and geographical conditions affect the location of the passing loops.

In order to capture this variability the analysed line designs are sampled so that the inter-loop distances vary around a specified mean distance. This procedure gives the opportunity to perform analysis of variance to see how variable inter-loop distances affect the measures of performance.

TVEM – a short model description

TVEM, Timetable Variant Evaluation Model, was constructed to evaluate the impact of traffic mix and infrastructure design on line capacity. The model is deterministic and generic. The fact that (most) passenger traffic is operated with periodic timetables is used to generate a large number of timetable variants. The spare capacity between the periodically operated traffic is then evaluated. Other features that might be evaluated are scheduled delays and utilisation of different passing loops.

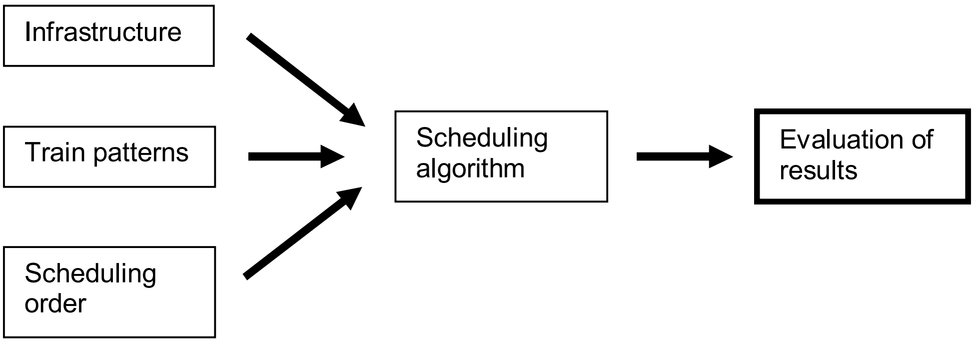


Figure 10 Structure of TVEM.

The scheduling algorithm is the heart of the model. Here, the train patterns are systematically scheduled according to their pre-defined (priority) scheduling order. Overtakings are introduced to resolve conflicts and track capacity is allocated at passing loopsfor this purpose.

All results are presented as distributions since different timetable variants result in different capacity, scheduled delays etc. The impact of the timetable design is thus displayed directly. It is also possible to vary the infrastructure design automatically in TVEM, and the impact of distances between passing loops can therefore also be evaluated.

Methods like TVEM are especially useful in planning stages where the timetable, i.e. frequency of operation, vehicle characteristics, stopping patterns etc, is unknown and one or several alternative infrastructure designs are to be evaluated.

In this project TVEM is applied to evaluate the effect of simple two-pattern mixes, i.e. operation with only two service types. The high-speed trains are given priority over the secondary trains (regional or freight trains), which means that all high-speed trains are scheduled first without any scheduled delays. The secondary trains are then fitted into the timetable between the high-speed trains. Capacity conflicts are resolved by introduction of overtakings on passing loops.

The analysed factors, i.e. inter-loop distance, speed level, frequency of service, stopping pattern and traffic mix, all affect the overtaking possibilities which in turn affects the measure of performance such as capacity, scheduled average speed of secondary trains etc.

Measures of performance

There is no evident way to measure capacity and timetable flexibility. The situation is even more complicated since the two traffic mixes analyzed within this assignment call for different measures of performance. This is because regional trains are operated according to a periodic timetable (whose frequency is strongly correlated to the frequency of the high-speed trains), whereas freight trains are operated one-by-one in non-periodic patterns.

Regional traffic

Three measures of performance are chosen for the regional traffic:

- Proportion feasible timetables.
- Average scheduled speed for regional trains.
- Standard deviation of scheduled speed for regional trains.

The proportion of feasible timetables is a straight forward measure of timetable flexibility since it shows the possibilities to change and adjust the timetable. The number of theoretical timetables is given by the timetable period, i.e. 30 or 60 minutes in this assignment. The measure shows how many percent of theses theoretical timetable alternatives that are feasible, i.e. that have not too much scheduled delay.

Timetable flexibility is useful when the timetable for a railway line is to be coordinated and synchronized to neighbouring lines. It is also necessary to have some flexibility to allow traffic to develop and grow.

The average scheduled speed for regional trains is a measure of time losses imposed by the traffic mix. The corresponding standard deviation is complementary and shows the impact of details in the infrastructure design, i.e. the importance of exact located passing loops etc.

Freight traffic

Three measures of performance are chosen for the freight traffic:

- Number of (possible) freight trains/h.
- Standard deviation for number of (possible) freight trains/h.
- Average scheduled speed for freight trains.

The number of freight trains/h is a pure capacity measure. It shows the spare capacity available in between the high-speed trains. Even if the line is not planned for this kind of dense freight traffic, this measure is a good indication of the capacity that can be used for other purposes than high-speed services. The standard deviation of number of freight trains is complementary and gives an idea about how sensitive the calculated capacity is to the exact inter-loop distances.

The average scheduled speed for freight trains indicates how mixed the traffic actually is. A high average speed means few overtakings and probably less sensitivity to disturbances etc.

All six measures of performance are meant to give a deep understanding of the operational features and possibilities of a double-tracked high-speed line.

Independent factors

Five independent factors are studied within this assignment:

- Average inter-loop distance.
- Traffic mix.
- Maximum speed for high-speed trains.
- Frequency of service for passenger trains.
- Stopping pattern for passenger trains.

All factors but the inter-loop distance are modelled on two levels. In order to gain more knowledge three different levels of the inter-loop distance are tested. This means that 48 unique variants are tested.

The **average inter-loop distance** is an important factor. Three levels are tested: 20, 40 and 60 km distance. The distance is here defined as the length of the double-track section between two adjacent passing loops. Real railway lines do not show a constant inter-loop distance. In order to simulate these fluctuations, each distance was randomized within an interval of the specified inter-loop distance ± 7.5 km.

This procedure gives a somewhat randomized design, which in turn calls for replicates, i.e. test of several line designs. For this reason 100 line designs were sampled for each of the 48 variants of the independent factors.

Two different **traffic mixes** are evaluated:

- High-speed and regional trains.
- High-speed and freight trains.

The **maximum speed** of the high-speed trains is another important factor. The higher this speed is, the more often do the high-speed trains have to overtake slower trains. Two levels of maximum speeds are evaluated: 250 and 300 km/h. The vehicle characteristics for these trains are shown in appendix 1.

The **frequency of service** is another factor that directly influences the overtaking pattern and the use of and need for passing loops. We assume and evaluate two levels: one high-speed train per hour and two high-speed trains per hour. Periodic operation (regular timetable) is presumed in both cases. For simplicity the regional trains are assumed to be operated at the same frequency as the high-speed trains.

In the case where the traffic mix consists of high-speed and freight trains, no special frequency is assumed for the freight trains. Instead, these trains are used to “fill up” capacity in between the high-speed trains to get a measure of the spare capacity.

The fifth factor chosen for evaluation is the **stopping pattern for the passenger trains**. This factor affects the average speed which in turn affects the need for overtakings. Two strategies for passenger stops are evaluated:

- Stop every 100 km for high-speed and every 50 km for regional trains.
- Stop every 150 km for high-speed and every 75 km for regional trains.

All stops are assumed to be located at passing loops, which means that the exact stopping location is adjusted to the sampled locations of crossing loops in each design replicate. The freight trains are assumed to be directly trains without any stops except situations when they are caught by faster trains and have to stop to be overtaken.

Constants

Several factors have been modelled as constants. The most important are:

Line length. The total line length was set to ca 400 km. A tolerance of ± 15 km was applied to allow the randomization of inter-loop distances to work properly.

Loop design. The loop design was chosen according to figure 3 and 4 with an entrance turnout with 130 km/h-speed restriction in the diverging track. The track length was hereby set to 585 + 100 m, see figure 3 and 4.

Headway. The minimum headway, used for scheduling, was set to 240 seconds. This means that a minimum buffer time for an overtaking is 70-85 seconds, since the technical headway is 155-170 seconds according to figure 9.

Accepted scheduled delay. The maximal accepted scheduled delay is an important constant. It is used to judge whether a train path is to be accepted or rejected. Too much scheduled delay means that the average speed of the service drops below the limit for market attractiveness. This is especially important for passenger services, but also freight services must not get too low average speeds. In this assignment we used an upper limit of 12% for the regional trains and 30% for the freight trains. This means that only train paths which suffer this less percentage scheduled delay is accepted.

Dwell times. The scheduled dwell times for passenger stop were assumed to be 120 seconds for high-speed services and 60 seconds for regional services.

Vehicle characteristics for regional and freight trains. The regional trains were operated with a maximum speed of 200 km/h. More detailed vehicle characteristics are shown in appendix 1. The freight train was a light freight train of 560 tons and maximum speed of 140 km/h. All vehicles have a deceleration of 0.8 m/s^2 which helps to make the overtaking courses time efficient.

Step length in scheduling. The step length in the scheduling procedure was one minute. This means that one hour has 60 theoretical time shifts, i.e. time locations for a train path.

Analysis of alternative inter-loop distances and operation for high-speed traffic mixed with regional traffic

The analysis of high-speed trains mixed with regional trains was performed in several steps, see figure 11. The chosen levels of the independent factors form 24 combinations of infrastructure design and operational conditions. These combinations were set up in the first step. The following five steps were executed for each of these 24 combinations.

Given the chosen average inter-loop distance (20, 40 or 60 km) 100 infrastructure designs, with slightly varying inter-loop distances were generated through randomization, see above for details.

The scheduling algorithm in TVEM was then applied on the replicates to seek alternative timetable solutions. The compilation of the number of feasible timetables found in this procedure forms the first measure of performance: the **proportion of feasible timetables**. This measure is calculated as the ratio between number of feasible timetables found for the evaluated mixed operation and the number of timetables in an unmixed situation without any high-speed trains. The measure is the average proportion of feasible timetables for the 100 replicates.

In the following step the “best” timetable variant found within each replicate was chosen to represent its infrastructure design. The two final measures of performance: **Average scheduled speed** and **Standard deviation of scheduled speed** were calculated from these best timetables.

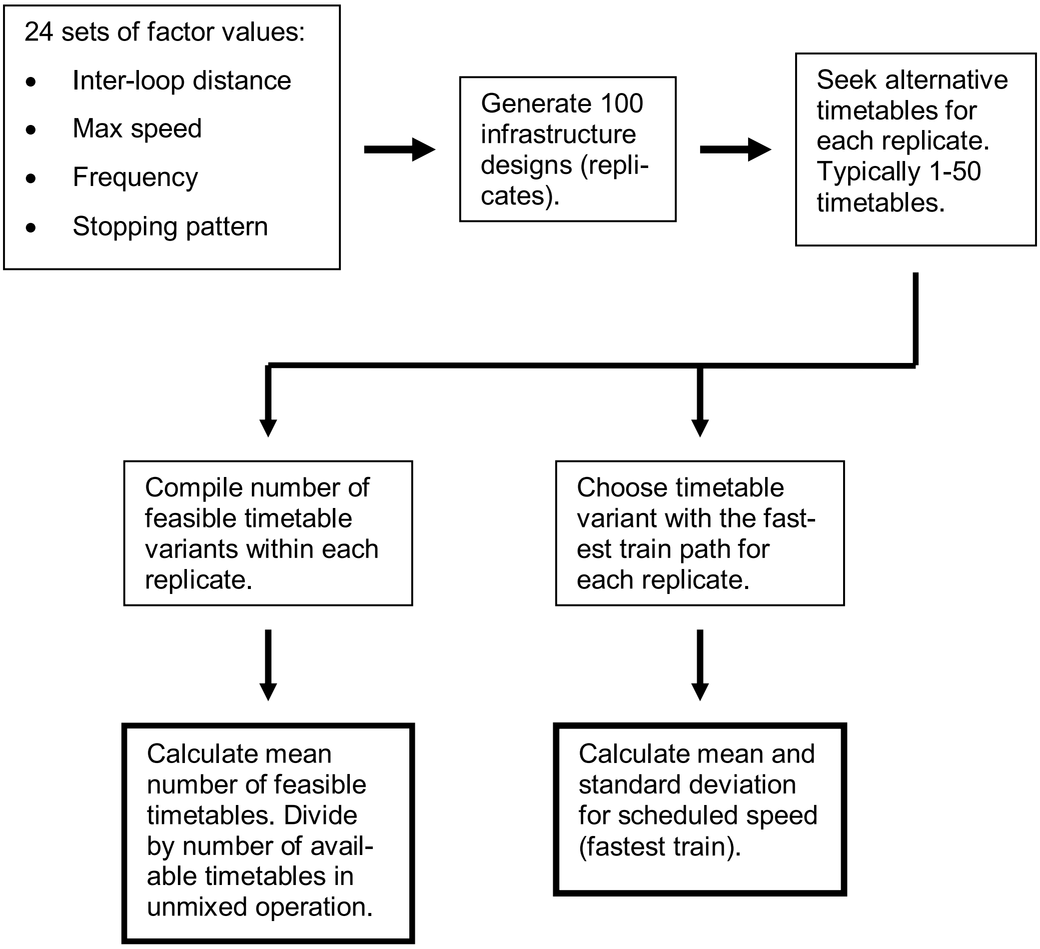


Figure 11 Evaluation steps for high-speed trains mixed with regional trains.

A mix of low-frequently operated high-speed trains and regional trains is a feasible traffic mix for a double-track railway system. Figure 12 shows the proportion feasible timetables found for each of the 24 evaluated infrastructure/operation variants.

The clearest result is that the frequency of service for the high-speed trains has a great impact on the timetable flexibility for regional trains. The lower frequency, one high-speed train/h, gives the opportunity to schedule regional trains without overtaking, which means that the number of passing loops does not restrict the number of alternative timetables very much.

The passing loops are much more important when high-speed frequency is high. This is seen both in a lower proportion feasible timetables and greater (relative) difference between different inter-loop distances. In other words, for the studied traffic mix the inter-loop distance is only a capacity concern when high-speed frequency is high.

The speed of the high-speed trains is more important for timetable flexibility when the frequency of service is low. Despite this difference the alternatives with 300 km/h and one high-speed train/h gives 20-40% feasible timetables for regional trains. This level could be regarded as acceptable.

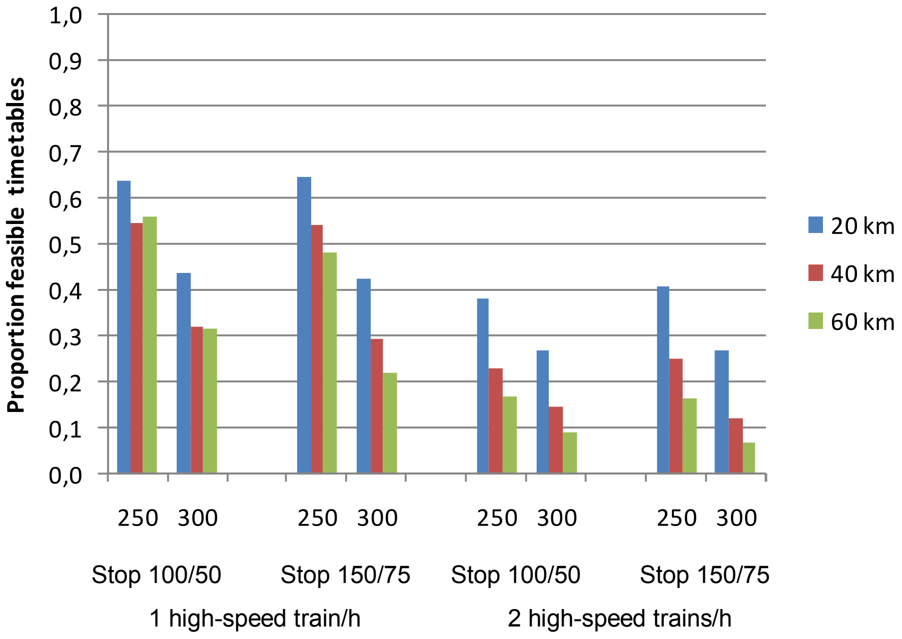


Figure 12 Proportion of feasible timetable variants (timetable flexibility).

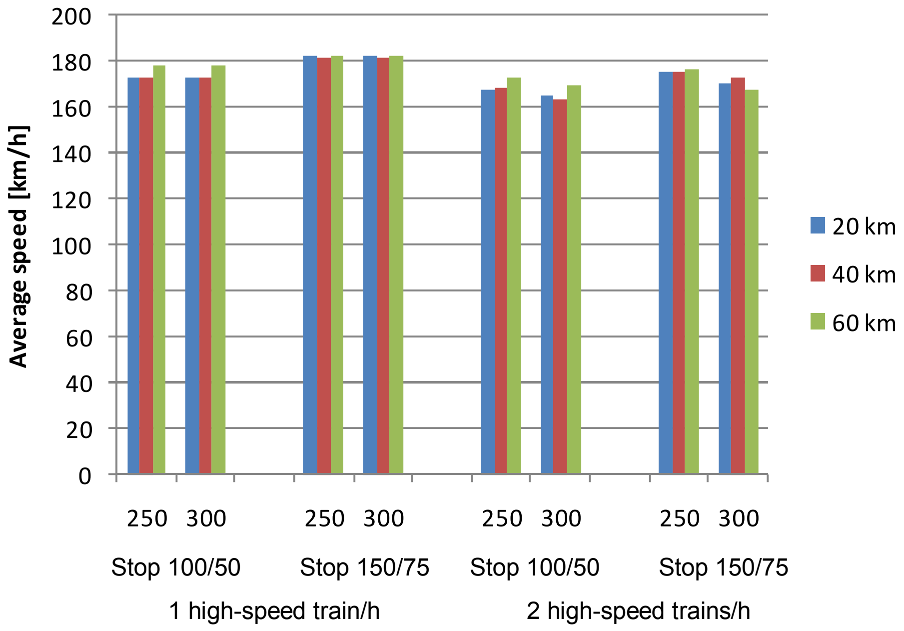


Figure 13 Average speed for regional trains.

The average speed of the regional trains depends on several factors. The overtaking pattern and use of passing loops is only one factor. Figure 13 shows the scheduled average speed for regional trains. The values shown are mean values of the fastest timetable within each replicate. These maximum speeds are only achieved in timetables where most overtakings are collocated with passenger stops and for infrastructure designs with feasible passing loop locations. In that sense they represent best-practice for this type of system and operation.

Figure 14 shows the speed standard deviation. This is a measure of the variability of achievable maximum speed among the replicates within each variant. The variability is limited for the low frequency of high-speed trains. This means that the exact inter-loop locations do not affect the speed of the regional trains very much.

The exact location of the passing loops is much more important in the most capacity consuming operation: high-speed trains at 300 km/h operated every half hour and with long distance between passenger stops.

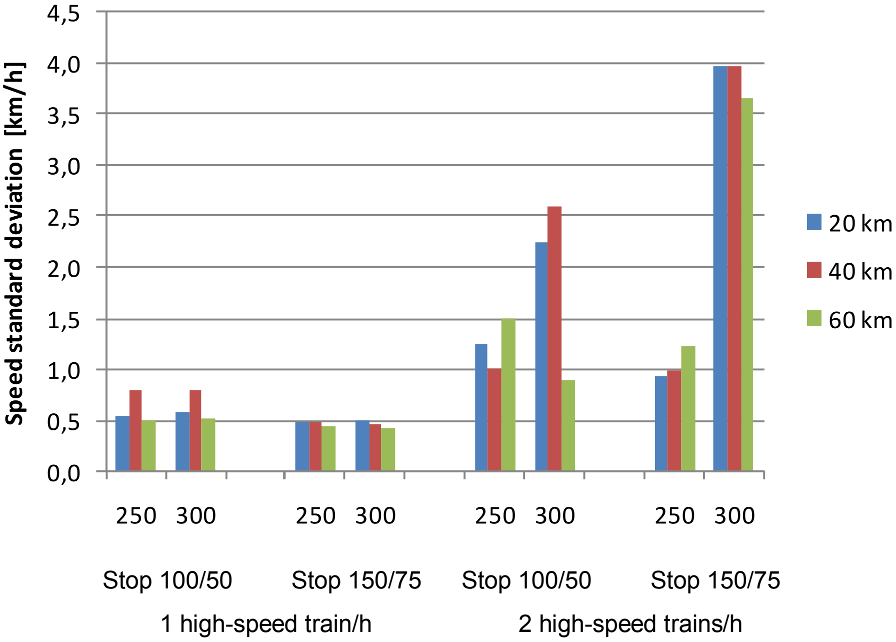


Figure 14 Speed standard deviation for regional trains.

Analysis of alternative inter-loop distances and operation for high-speed traffic mixed with freight traffic

The evaluation of high-speed trains mixed with freight trains was performed in a similar way to the evaluation of high-speed and regional trains. Also in this case the chosen levels of the independent factors form 24 combinations of infrastructure design and operational conditions. These combinations were set up in the first step. The following five steps were executed for each of the 24 combinations.

Given the chosen average inter-loop distance (20, 40 or 60 km) 100 infrastructure designs, with slightly varying inter-loop distances were generated through randomization, see above for details.

The scheduling algorithm in TVEM was then applied on the replicates to schedule as many freight trains as possible between the high-speed trains. The compilation of the number of scheduled freight trains gave the two first measures of performance: the **Mean number of scheduled freight trains and** the **Standard deviation for number of possible freight trains**. The measure is the average number of freight trains/h possible within the 100 replicates.

In the final step the **average speed of scheduled freight trains** was compiled.

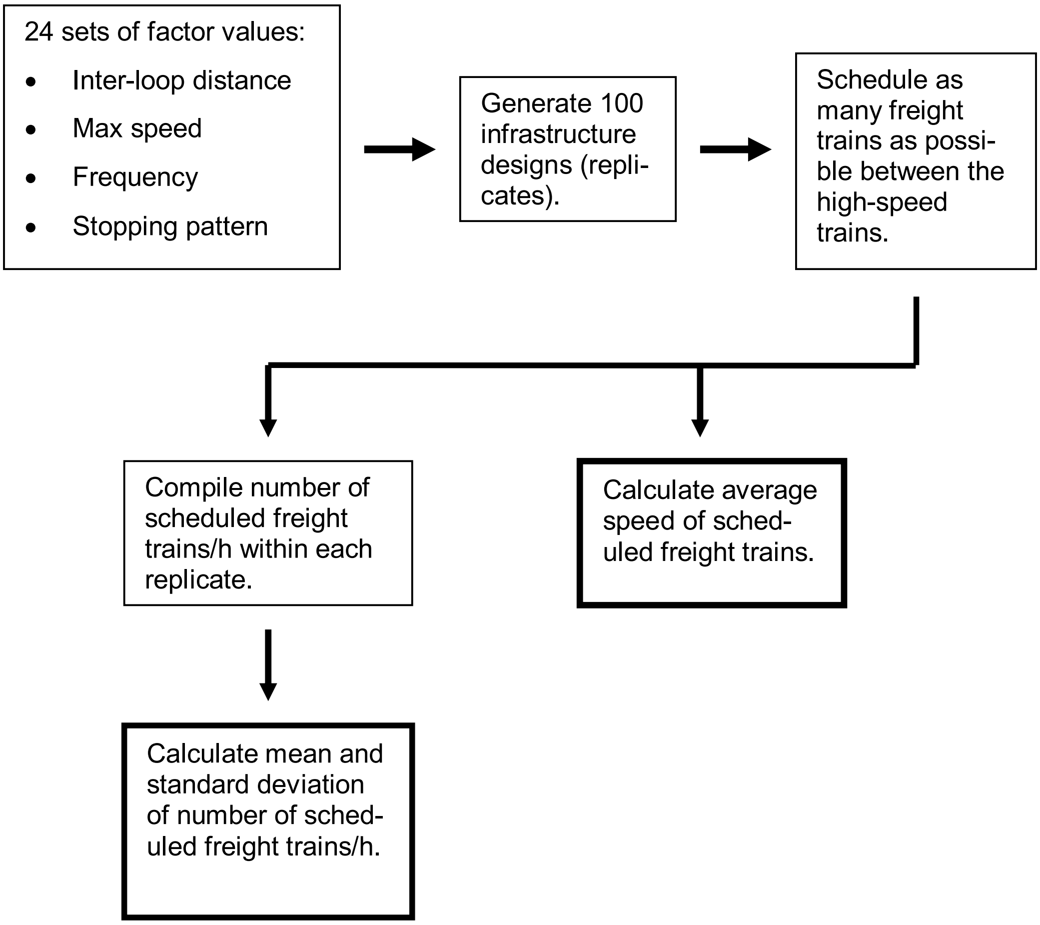


Figure 15 Evaluation steps for high-speed trains mixed with freight trains.

A mix of low-frequently operated high-speed trains and fast freight trains (140 km/h) is also a possible traffic combination for at double-track system. Figure 16 shows that at least one freight train/h is possible in all variants but one. Several of the variants show very high capacity for freight trains, 4-11 trains/h.

It is seen that the inter-loop distance is of great importance. It is possible to compensate a high maximum speed and/or frequency of service with a shorter inter-loop distance. The maximum speed of high-speed trains does not affect freight train capacity very much when the frequency of service is only one train/h. A higher frequency of high-speed trains results in a higher sensitivity to the inter-loop distance.

The effect of passenger stops is also limited when the high-speed frequency is only one train/h. However, a greater impact of the passenger stops is seen for the higher frequency of service.

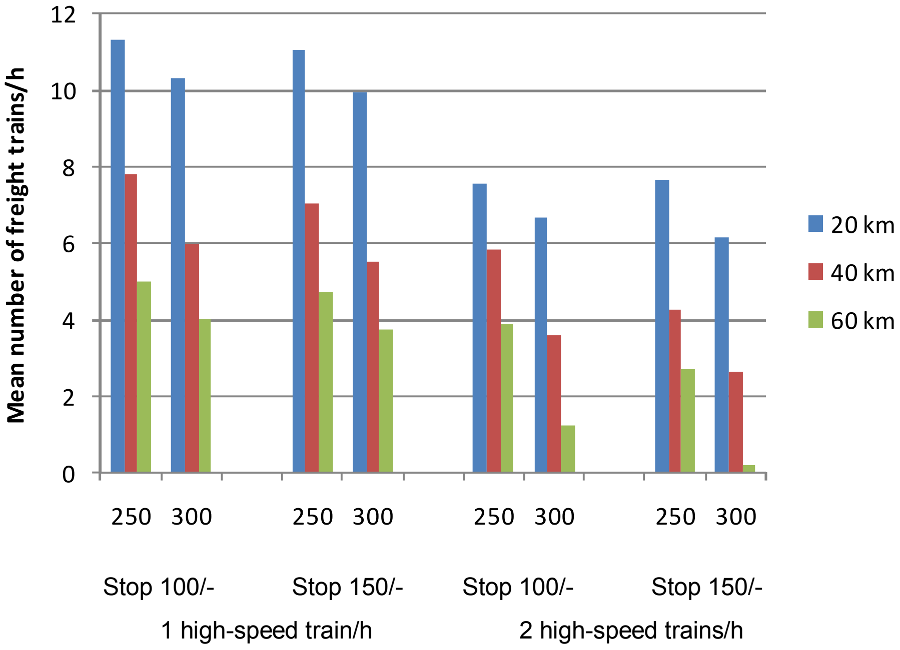


Figure 16 Mean number of possible freight trains/h.

The numbers of freight trains presented in figure 16 are mean values over 100 replicates, i.e. 100 sampled infrastructure designs for each variant. The exact location of the crossing loops also affects the capacity. This variance is displayed in figure 17 which shows the standard deviation of number of freight trains/h.

It is seen that the location of the passing loops affects capacity in most of the 24 tested variants with a standard deviation greater than zero. It is worth noticing that the importance of the loop locations is highest for the variants with lower capacity, i.e. fast and high frequent passenger traffic. These cases therefore call for more careful location planning of the passing loops.

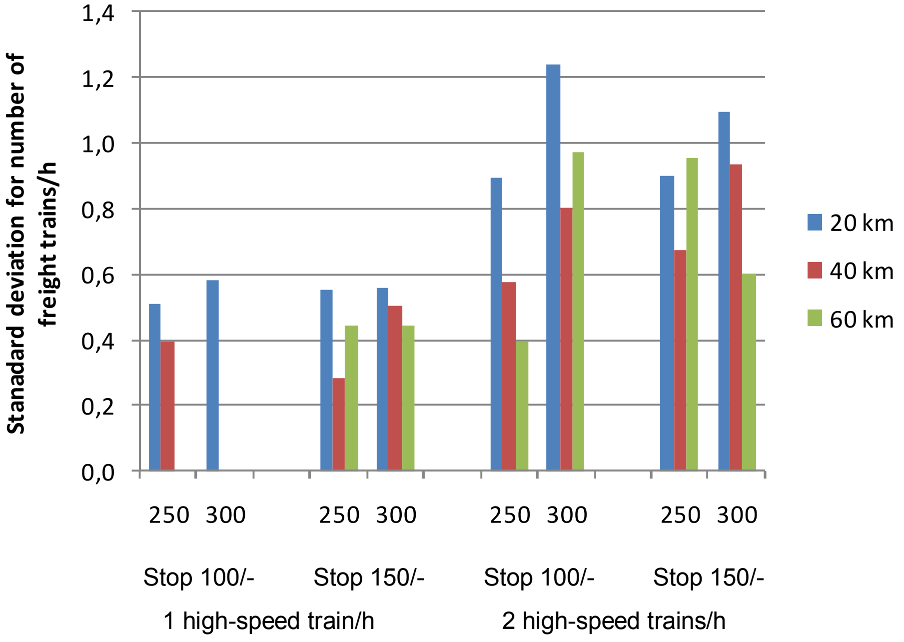


Figure 17 Standard deviation for number of possible freight trains/h.

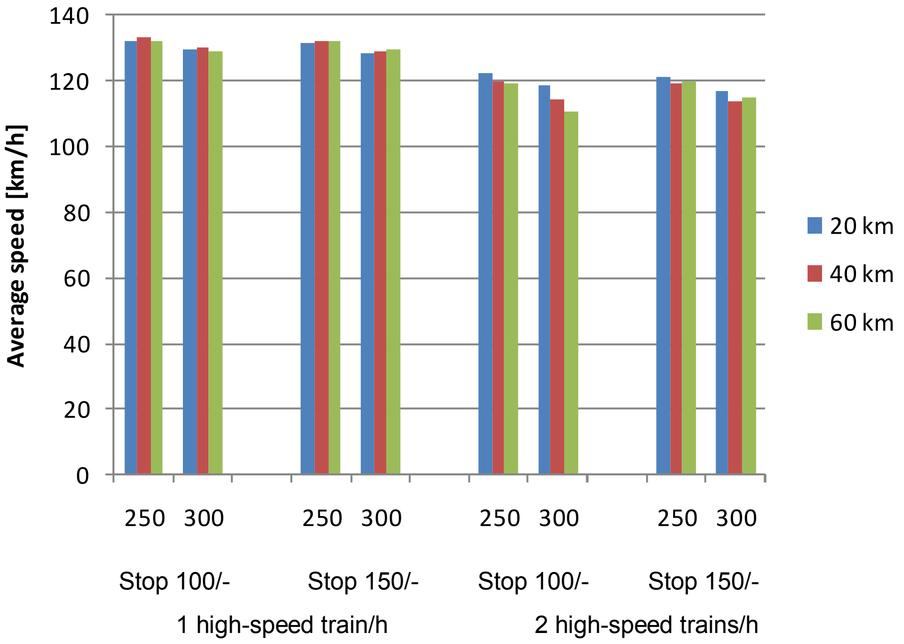


Figure 18 Average speed for freight trains.

The freight trains have a maximum speed of 140 km/h. This means that they are scheduled at this speed as long as they do not conflict with faster trains. However, such conflicts occur and they are resolved by time consuming overtakings which imply lower average speeds.

Figure 18 shows the average speed for all freight trains scheduled within each variant. The low frequent high-speed traffic implies fewer overtakings which in turn results in higher average speeds for freight trains. It is remarkable that neither inter-loop distance, nor speed or stopping pattern for high-speed trains affect the freight train speed very much.

A higher frequency of service implies more overtakings and lower average speeds. The differences between different variants are still rather small. The conclusion is that the inter-loop distance affects capacity (and probably also of operational quality), but not the achievable average speed of the freight trains.

Conclusions

This report addresses the design of passing loops and the distance in-between them. These parameters are essential in the design of double-track railway systems due to their direct impact on capacity, scheduled delays (run times) and knock-on delays.

The design of each passing loops is mainly a matter of scheduled delays, i.e. how time efficient overtakings should be made possible. The evaluation of different designs and traffic situations resulted in the following recommendations:

- Speed in entrance turnout (diverging track): 130 km/h.
- Length of loop track (between signals): 685 m
- Speed in exit turnout (diverging track): 100 km/h.
- Combined overtaking and passenger stop is a very efficient way to minimize the scheduled delay and reach a high average speed for the overtaken train.

The technical design values (three first points) give a scheduled delay of 155-170 s, depending on the operational situation. If the overtaking is combined with a passenger stop the delay is only 20 s.

The loop spacing is a much more general task since it affects both capacity and scheduled and knock-on delays. The analysis of different inter-loop distances shows that a high-speed line operated by one high-speed train/h (and direction) also manage regional trains every 60 or 30 minutes. Even if the high-speed frequency is increased to two trains/h there will be capacity for regional train with the same frequency.

For a mix of high-speed and regional trains the following recommendations, regarding inter-loop distances, can be made:

- 60 km inter-loop distances for lines planned for one high-speed train/h.
- 20-40 km inter-loop distances for lines planned for two high-speed trains/h.
- Special care has to be paid for the exact locations of the loops. This is most important when the high-speed traffic is operated with two trains/h.

The distances are between two adjacent loops whose loop track is directly available from the main track for the actual direction, i.e. without intersecting routes with opposing traffic.

The analysis also shows that there is capacity for freight traffic, provided that these trains are fast (140 km/h) and have similar characteristics as the passenger trains (acceleration and deceleration). The frequency of the high-speed trains and the inter-loop distances are very important for the freight capacity. The speed of the high-speed trains is also important when this traffic is operated with two trains/h.

The analysis shows that the recommendations for high-speed plus regional trains also hold for high-speed plus freight:

- 60 km inter-loop distances for lines planned for one high-speed train/h.
- 20-40 km inter-loop distances for lines planned for two high-speed trains/h.

These inter-loop distances will make it possible to operate 2-4 freight trains/h. However, also this traffic mix is sensitive to the exact location of the passing loops when the high-speed frequency is high (2 trains/h).

Even if this amount of freight traffic might not seem realistic, the evaluation indicates that there is spare capacity between the high-speed trains. The two traffic mixes analyzed in this report are rather simple ones. If the mix becomes more complicated, including more than two types of traffic, the capacity is likely to drop and the scheduled delay to rise.

It possible to perform the corresponding analysis for other, more complex, mixes but such analyses requires either more knowledge of future traffic scenarios or detailed assumptions to limit the evaluation space.

Further studies

The recommendation is to perform further studies within the following fields:

- Knock-on delays and further requirements for time supplements to cope with delay propagation. This work has to be performed for infrastructure designs and timetable structures that are likely to become reality or is found to be representative to a coming real situation.
- The possibility to locate passing loops either between the main tracks so that the loop track is available for both up- and down bound trains or alternately on up- and down side of the railway. This is of interest since some types of operation makes it possible also to utilise loop tracks that are located on the “wrong side”, causing intersecting routes.
- The effect of halts on the line, i.e. passenger stops on main tracks without possibility to simultaneous overtaking. Halts will probably impose shorter inter-loop distance for these line sections in order to keep the time distance between adjacent loops on a reasonable level.
- The impact of gradients.
- Analysis of impact of bad weather conditions, low friction conditions.
- Optimal train performance, top speed, acceleration etc.
- Power and energy consumption.
- Possibilities for eco driving and optimal train control, thus increasing punctuality.

References

Lindfeldt, O., (2010). *Railway operation analysis – Evaluation of quality, infrastructure and timetable on single and double-track lines with analytical models and simulation*, Thesis (PhD), Stockholm.

Appendix 1

Loop design

Overtaking train: Velaro E, utilized top speed 300 km/h, length 200 m.

Overtaken train:

- Regional train: Generic (same as in Crossing loops), top speed 200 km/h, length 200 m
- Freight train: weight 564 tons, top speed 140 km/h, length 157 m

Loop spacing

Overtaking train:

- 300 km/h: Velaro E, top speed 300 km/h, length 200 m
- 250 km/h: : Generic (same as in Crossing loops), top speed 250 km/h, length 200 m

Overtaken train:

- Regional train: Generic (same as in Crossing loops), top speed 200 km/h, length 200 m
- Freight train: weight 560 tons, top speed 140 km/h, length 157 m

Train data

Table A1. Basic train data for ICE3 Velaro, Generic EMU and Generic freight train of uniform consist on level track.

	ICE3 Velaro E	Regional Generic EMU	Freight train Covered type Wagons
Speed in study	Utilized top speed in study: 300 km/h (maximum top speed 350 km/h)	200 km/h	140 km/h
Max power	8800 kW	9600 kW	5600 kW
Starting effort	280 kN	353 kN	300 kN

Starting acceleration Level track	0.60 m/s^2	0.70 m/s^2	0.49 m/s^2
Average deceleration	0.8 m/s^2	0.8 m/s^2	0.80 m/s^2
Acceleration time to top speed	300 s (0-300 km/h)	125s (0-200 km/h)	115 s (0-140 km/h)
Acceleration distance to top speed	17000 m (0-300 km/h)	4100 m (0-200 km/h)	2700 m (0-140 km/h)
Mass	440 t	420 t	564 t
Length	200 m	200 m	157 m

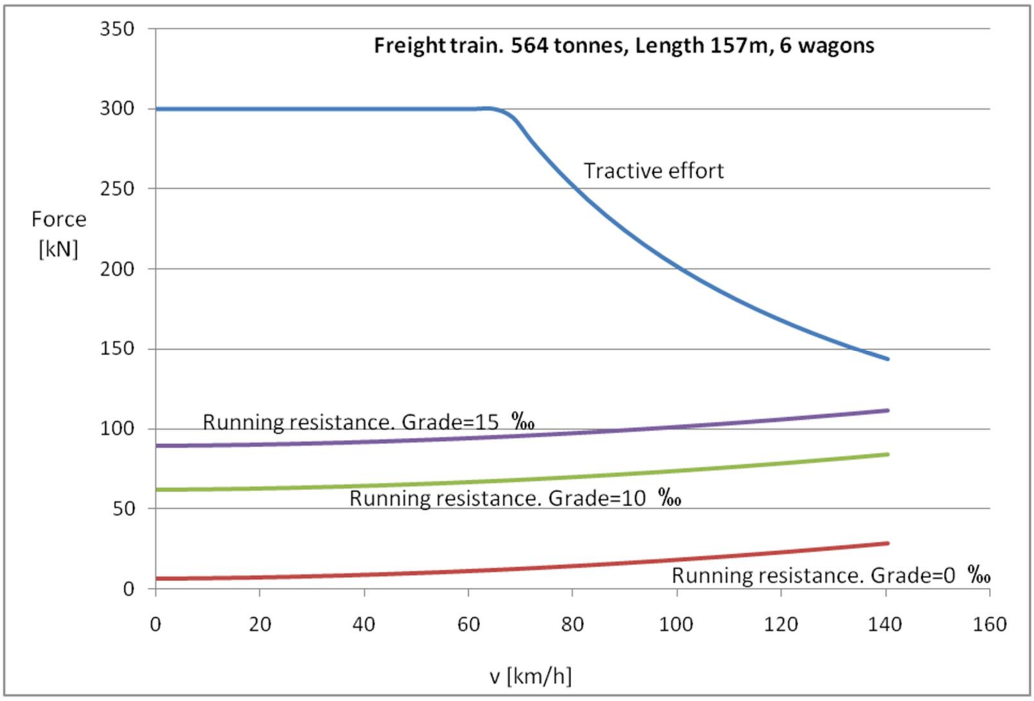


Figure 19. Tractive effort and running resistance for the generic freight train in grades of 0, 10 and 15 permille. The generic freight train in this study represents a “light freight train” designed to run at 140 km/h. Length 157 m, mass 564 tonnes, 6 wagons.

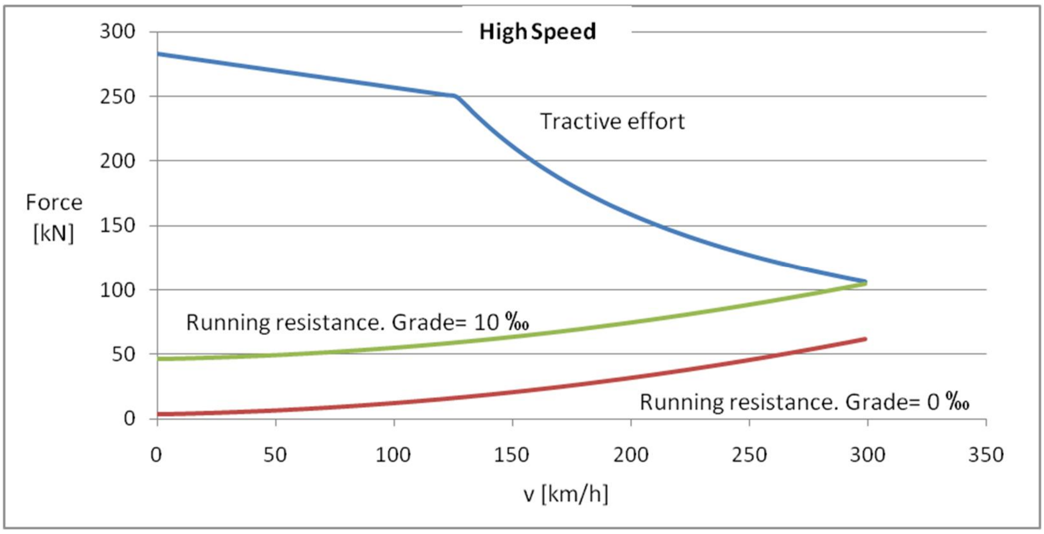
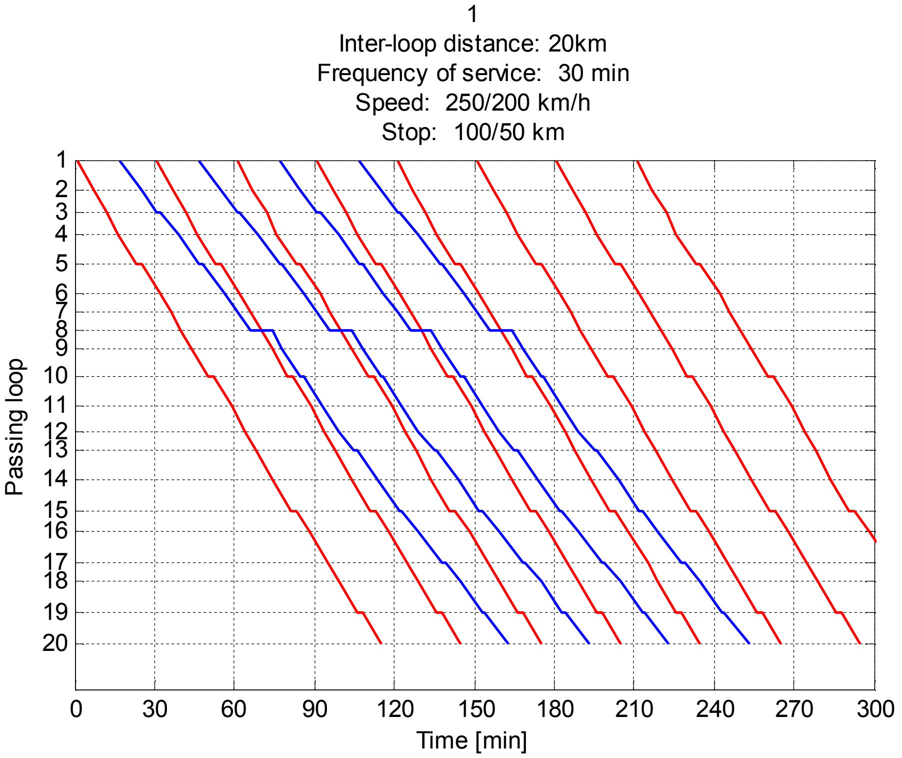


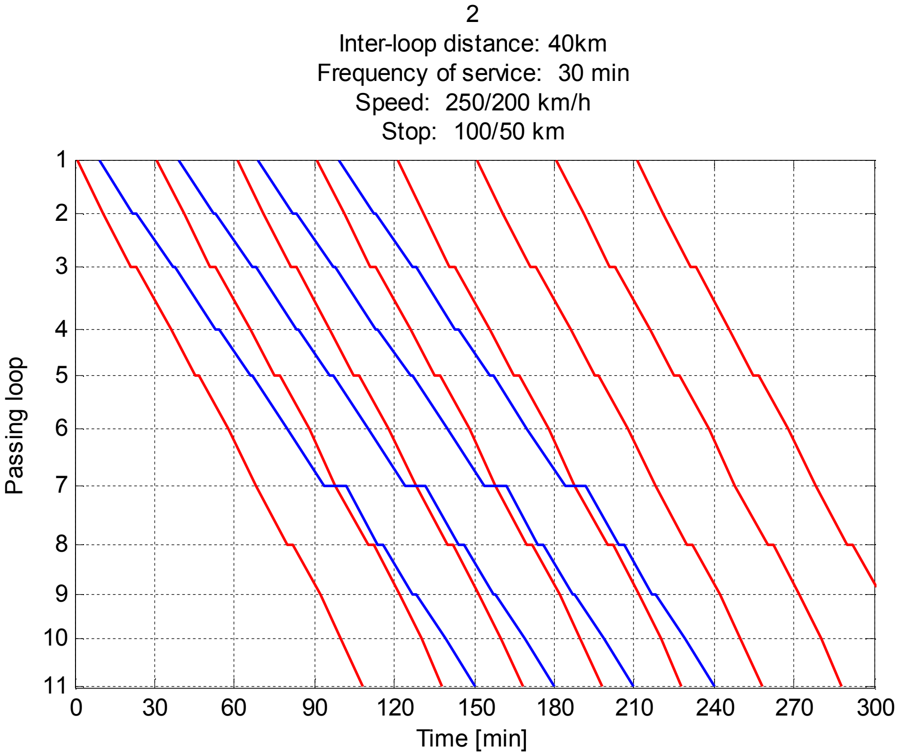
Figure 20. Tractive effort and runnnig resistance for ICE3 Velaro- E in grades of 0 and 10 permille up to 300 km/h (ICE3 Velaro can run up to a speed of 350 km/h).

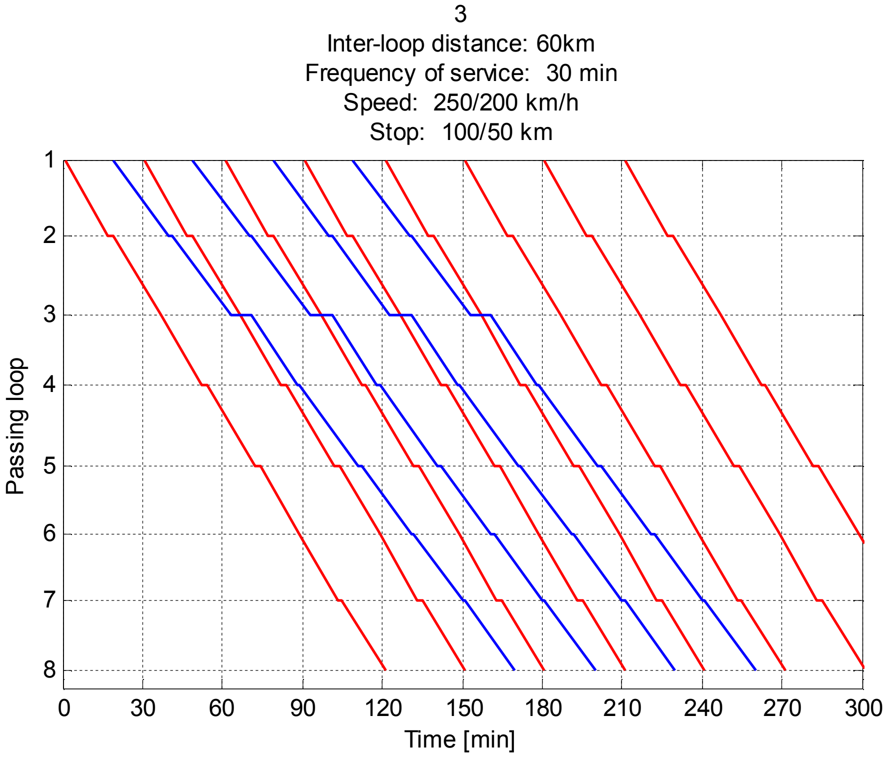
The performance of the generic EMU is similar to that of ICE3- Velaro, up to a speed of approx. 250 km/h

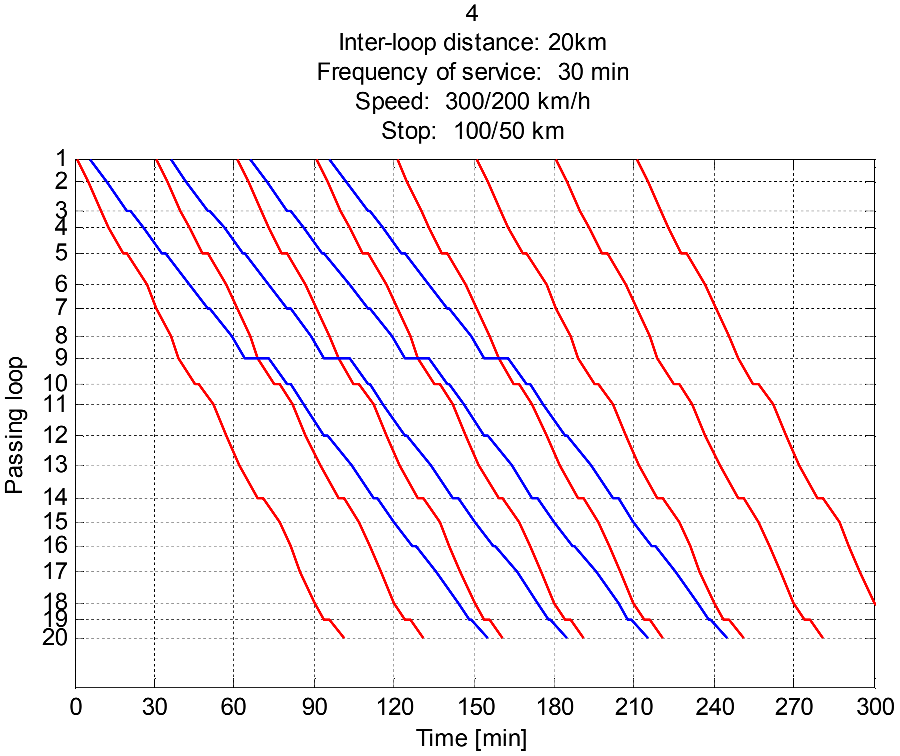
Appendix 2

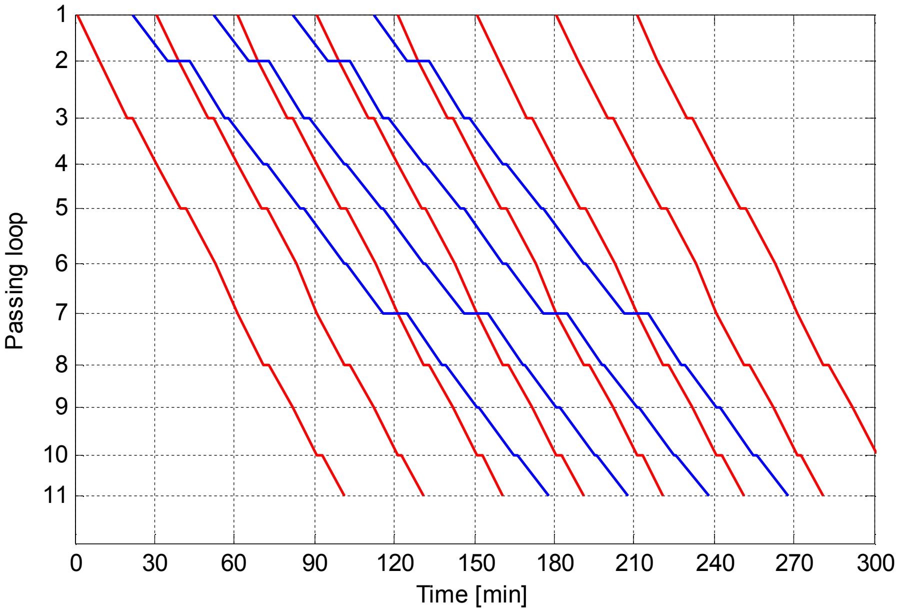
Examples of timetables for different combinations of inter-loop distance, frequency of service, speeds and stop patterns. High-speed trains mixed with regional trains.



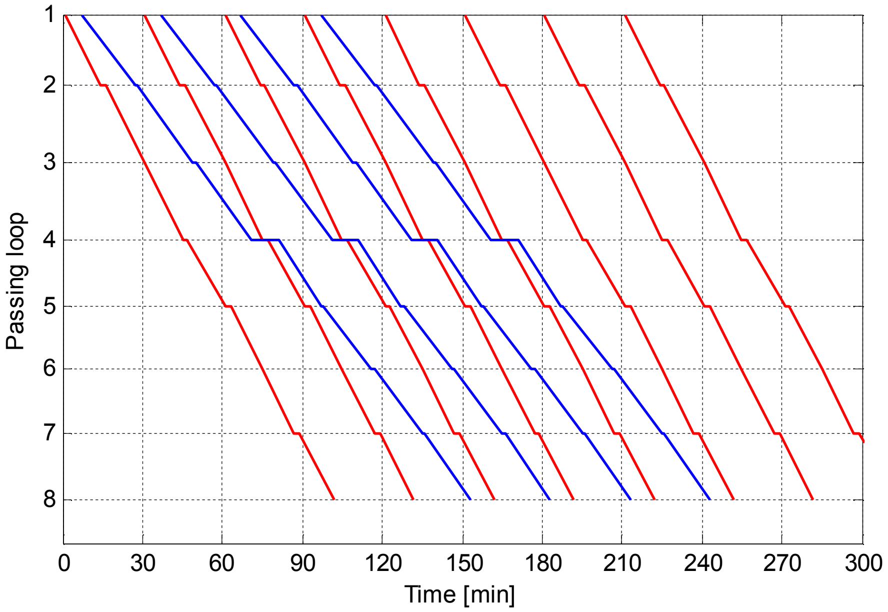



3
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 250/200 km/h
Stop: 100/50 km


4
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 100/50 km

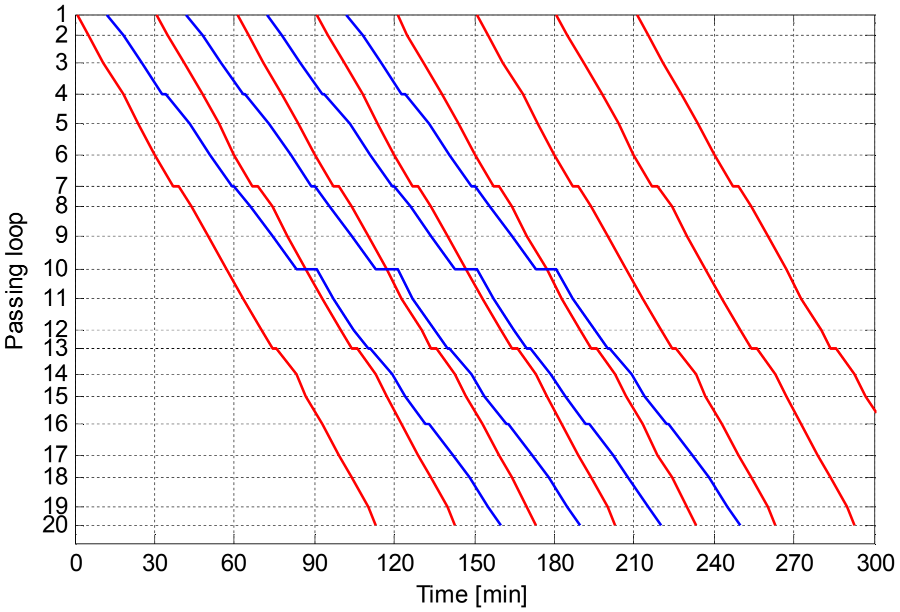


5
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 100/50 km

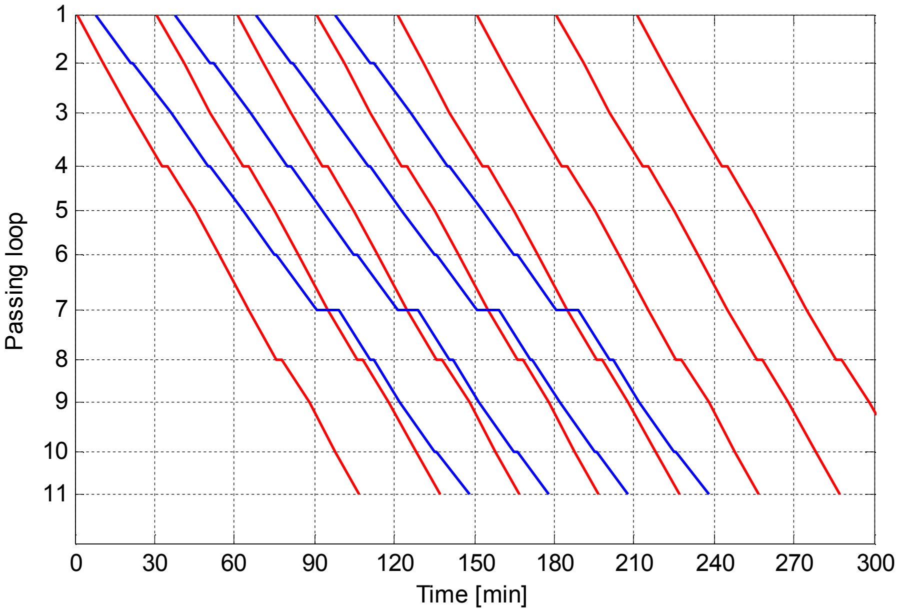


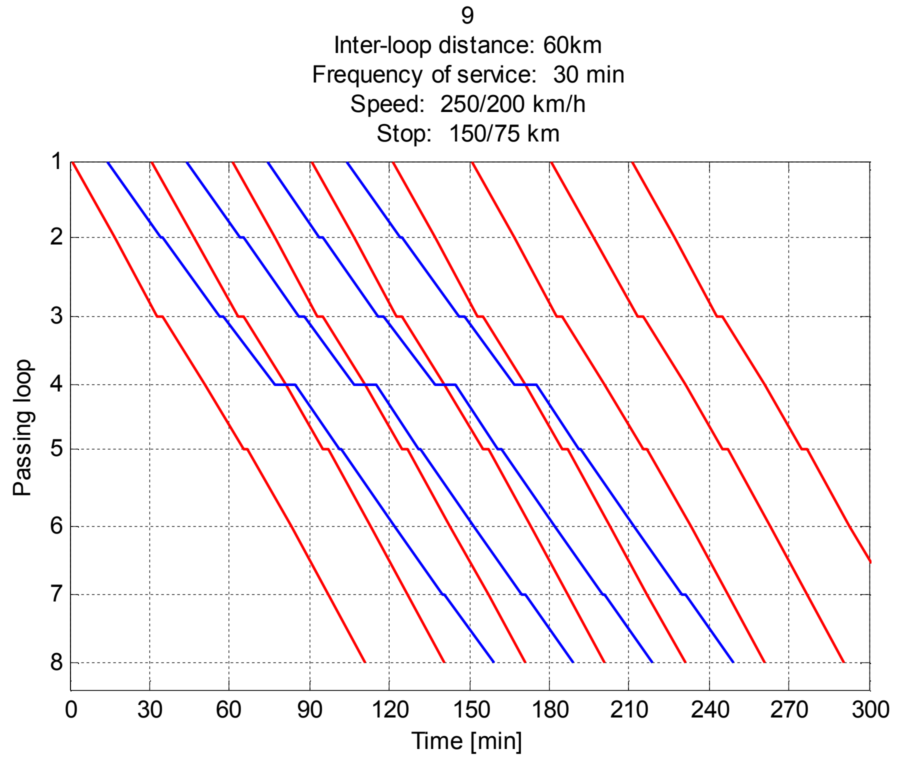
6
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 100/50 km

7
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 250/200 km/h
Stop: 150/75 km



8
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 250/200 km/h
Stop: 150/75 km




9
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 250/200 km/h
Stop: 150/75 km
Passing loop
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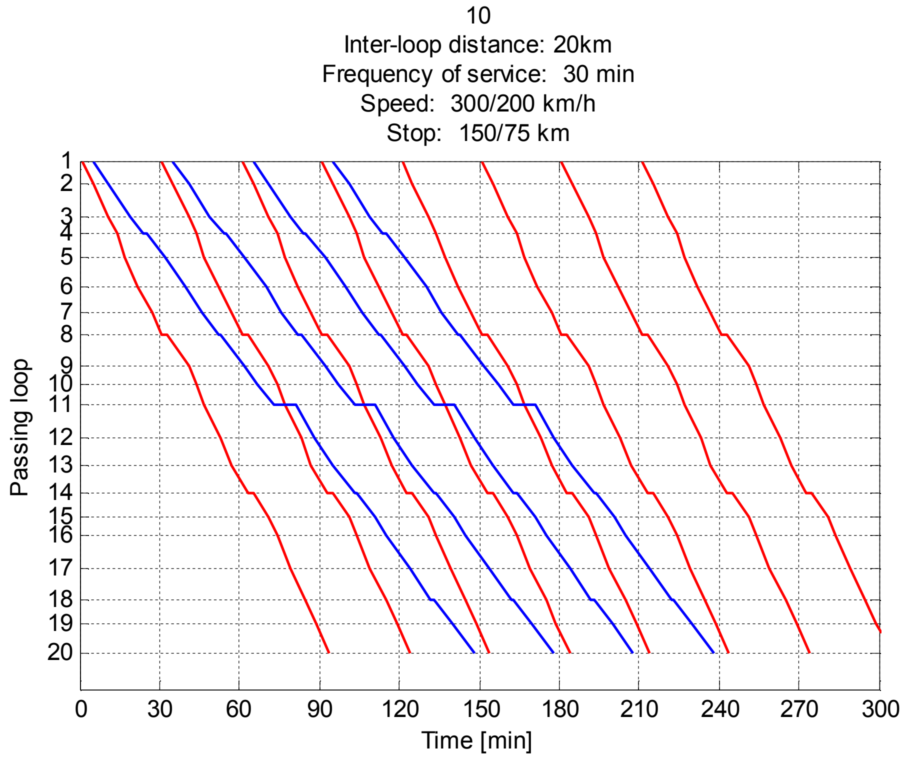
Time [min]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Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 150/75 km
Passing loop
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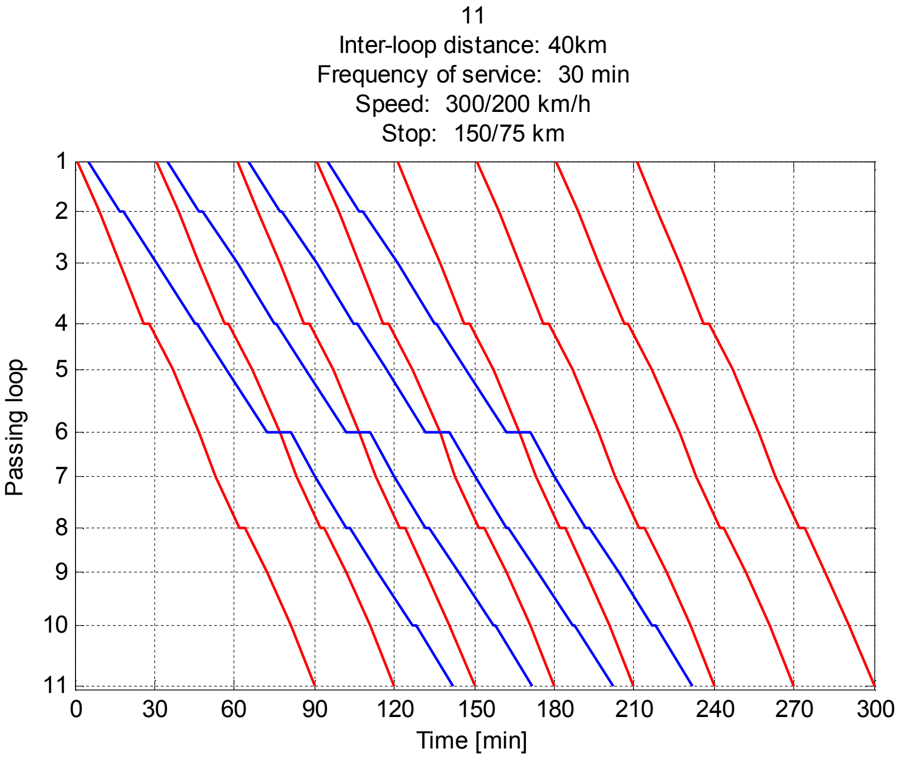
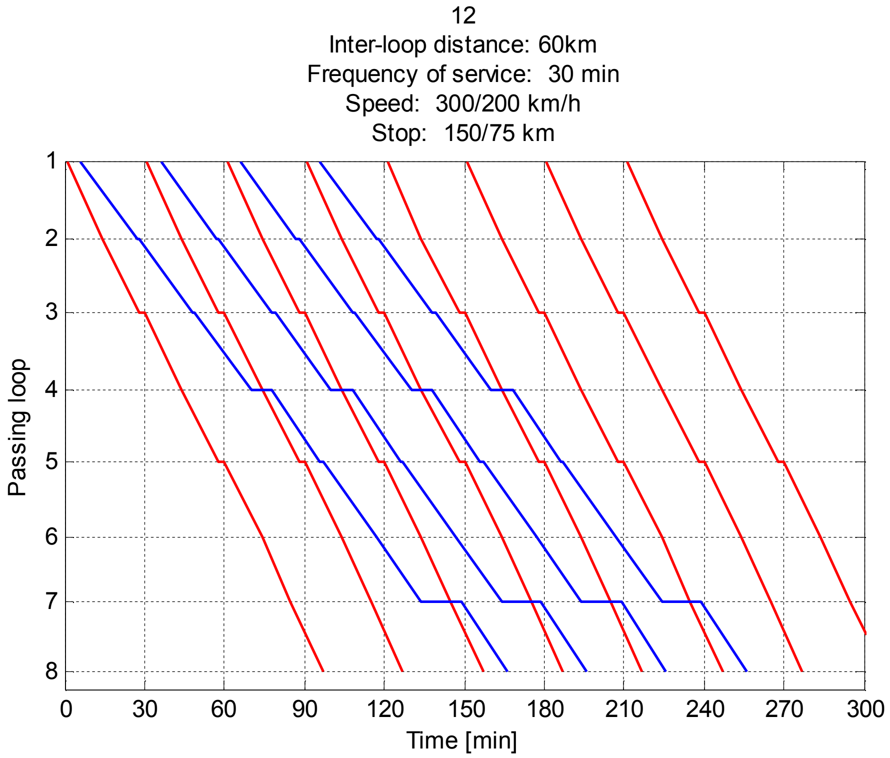
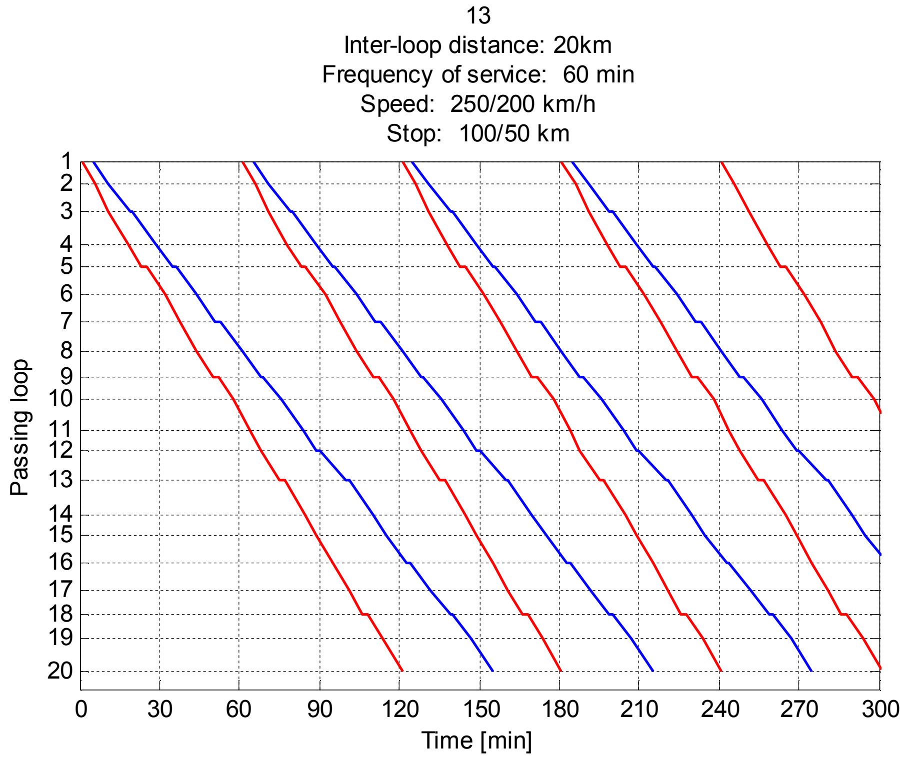
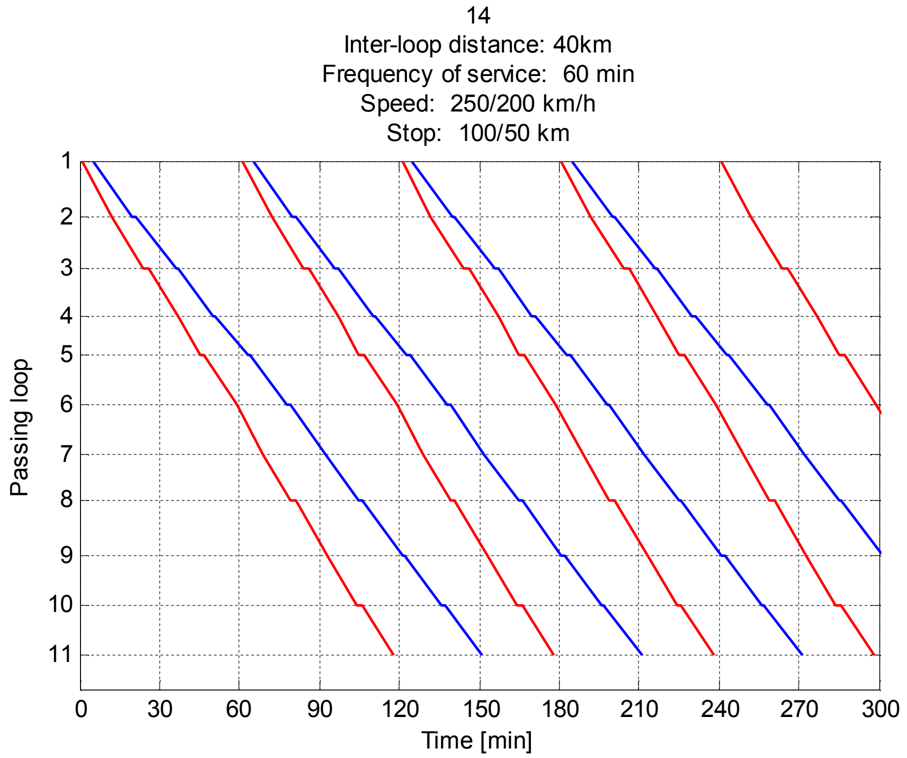
Time [min]


11
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 150/75 km

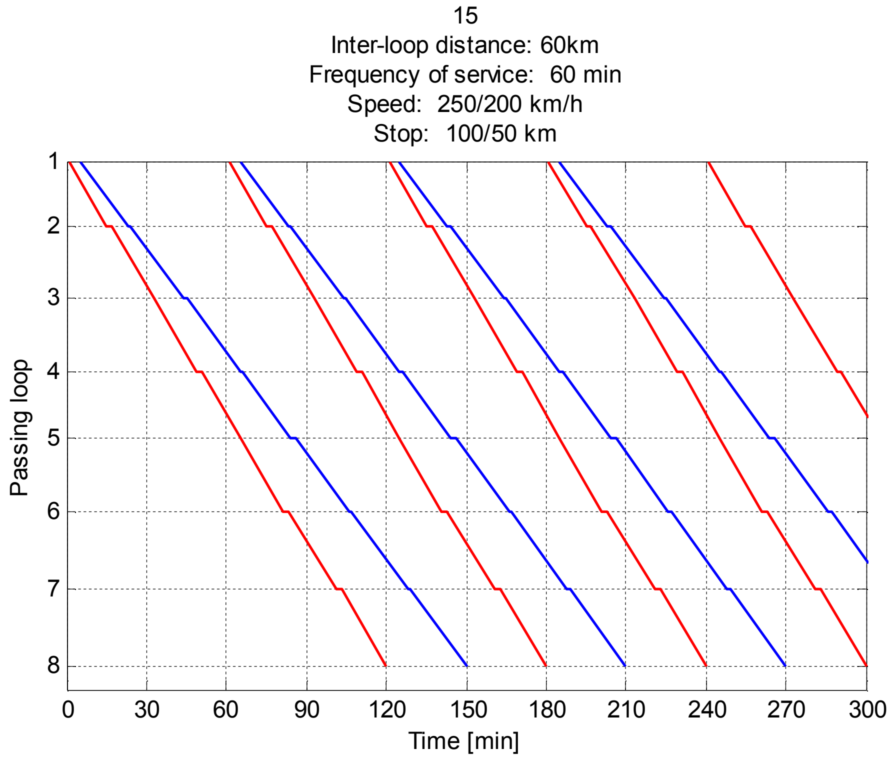

12
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 300/200 km/h
Stop: 150/75 km



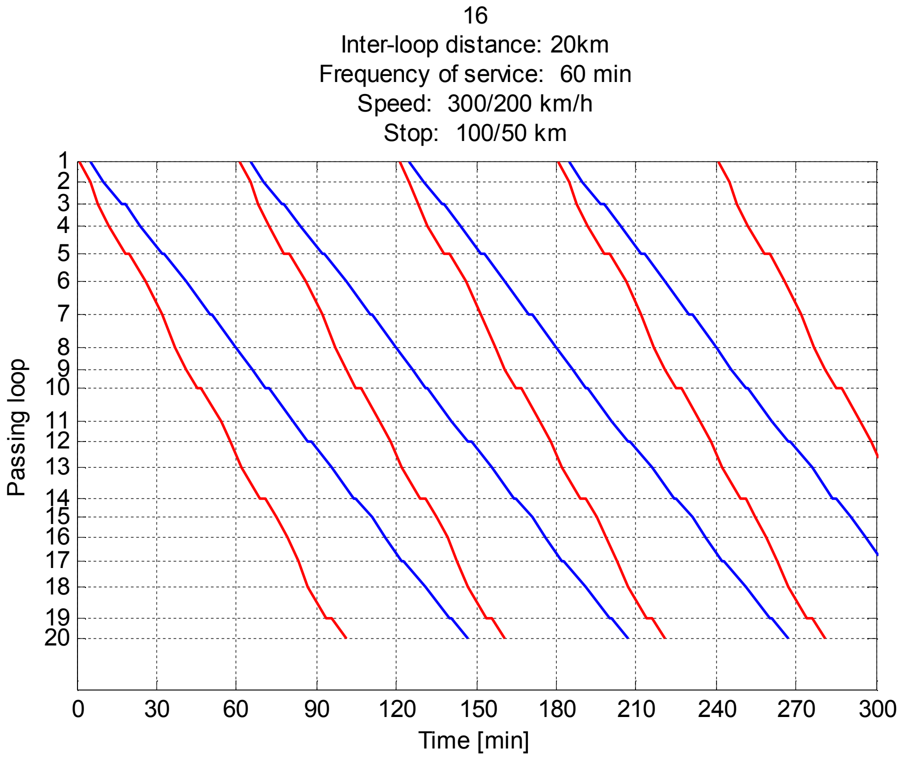
13
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 100/50 km



14
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 100/50 km



15
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 100/50 km



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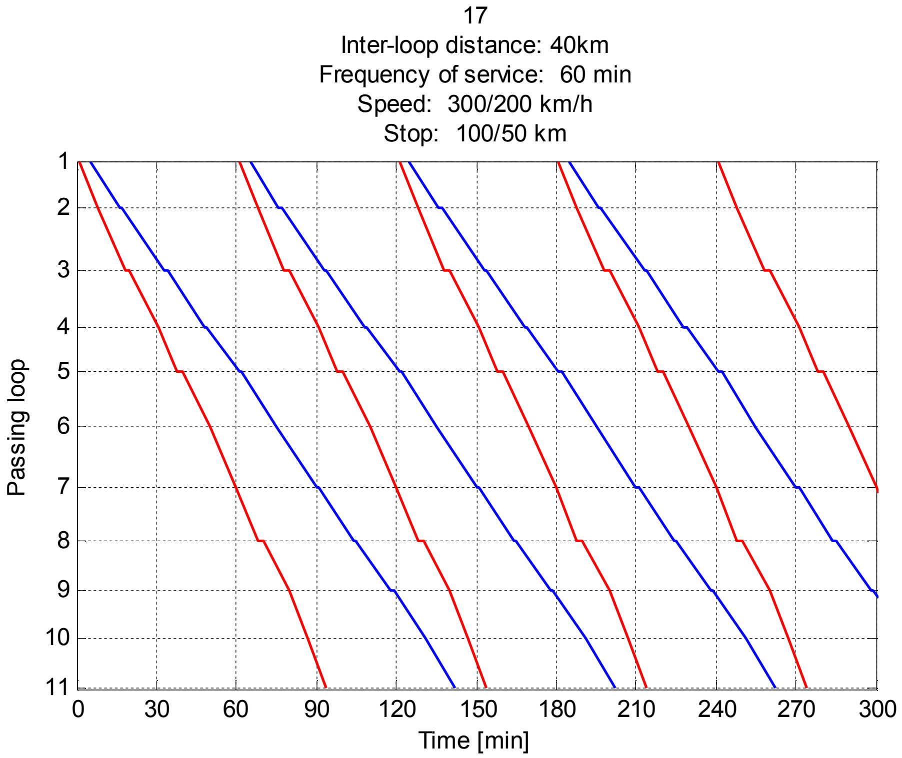
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 100/50 km


17
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 100/50 km
Passing loop
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Time [min]
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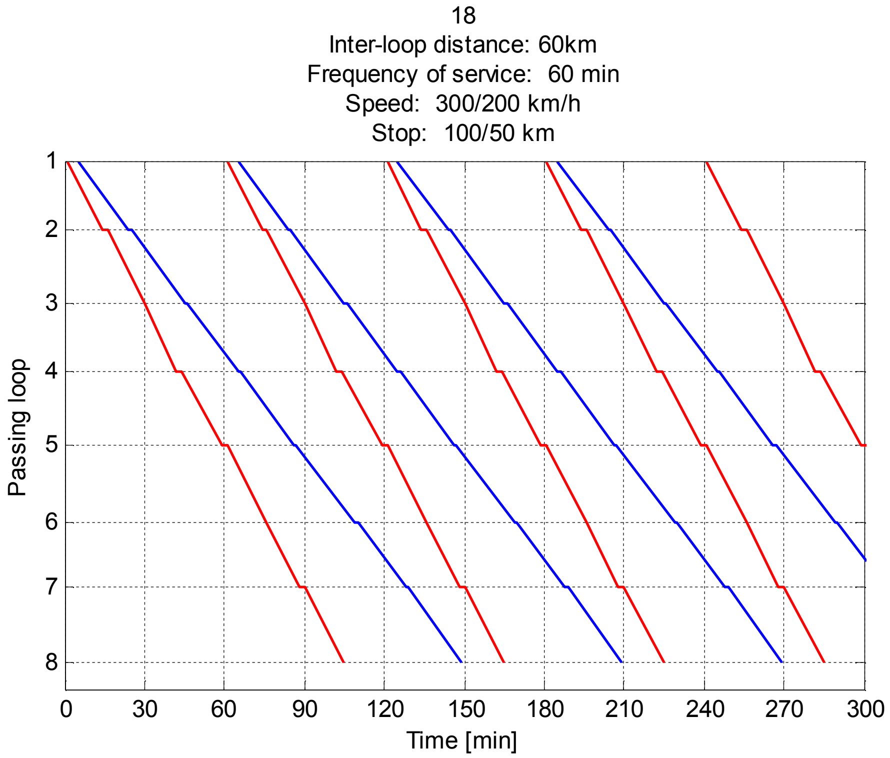
18
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 100/50 km
Passing loop
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Time [min]
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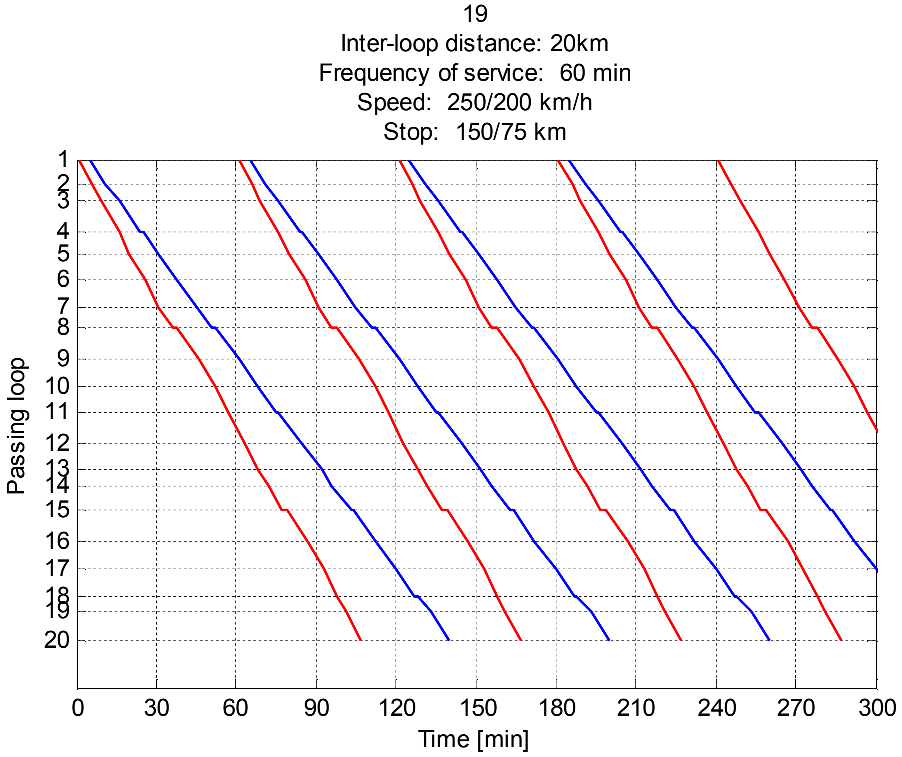
19
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 150/75 km
Passing loop
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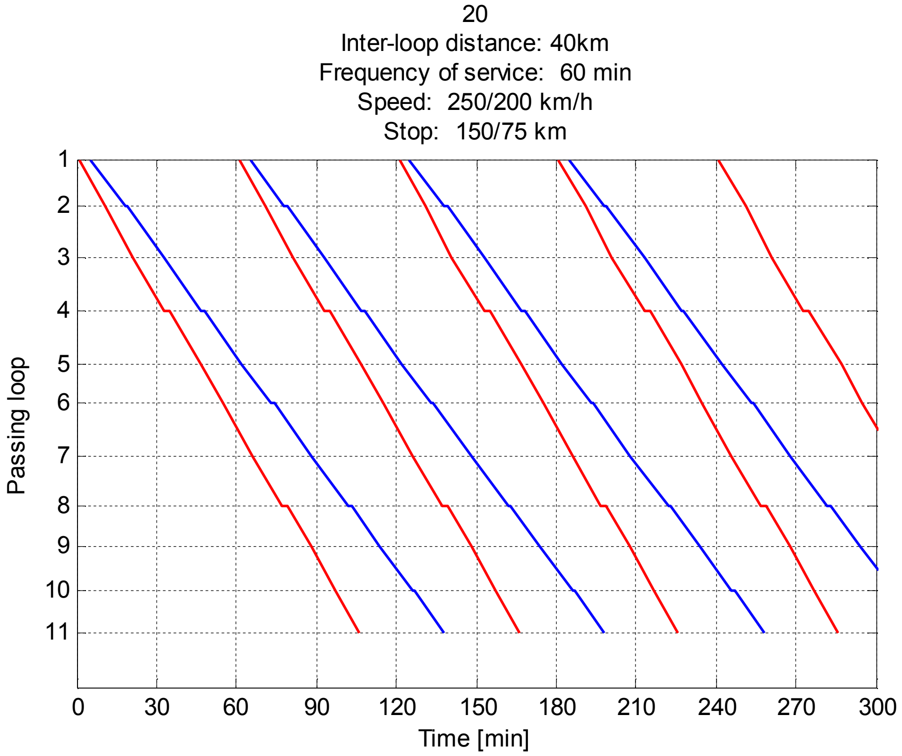
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Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 150/75 km
Passing loop
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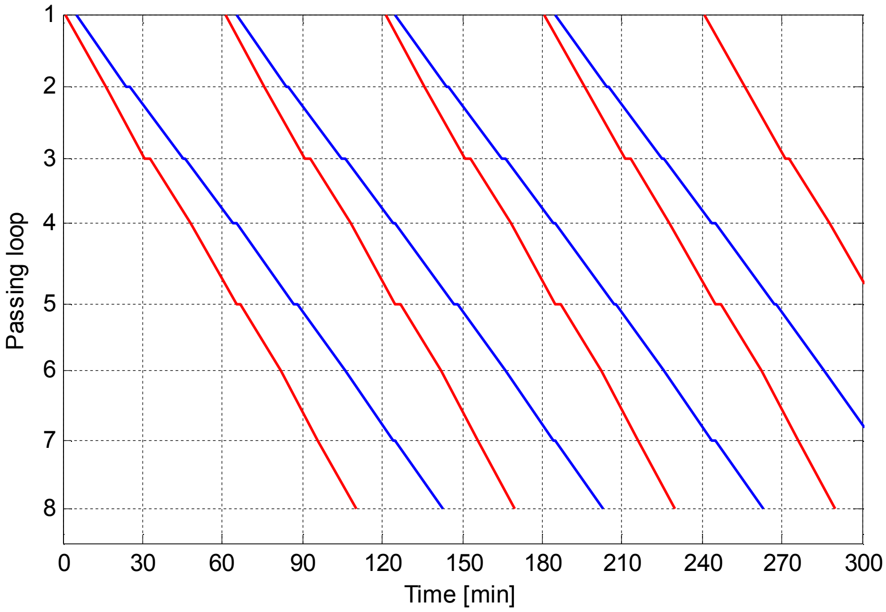
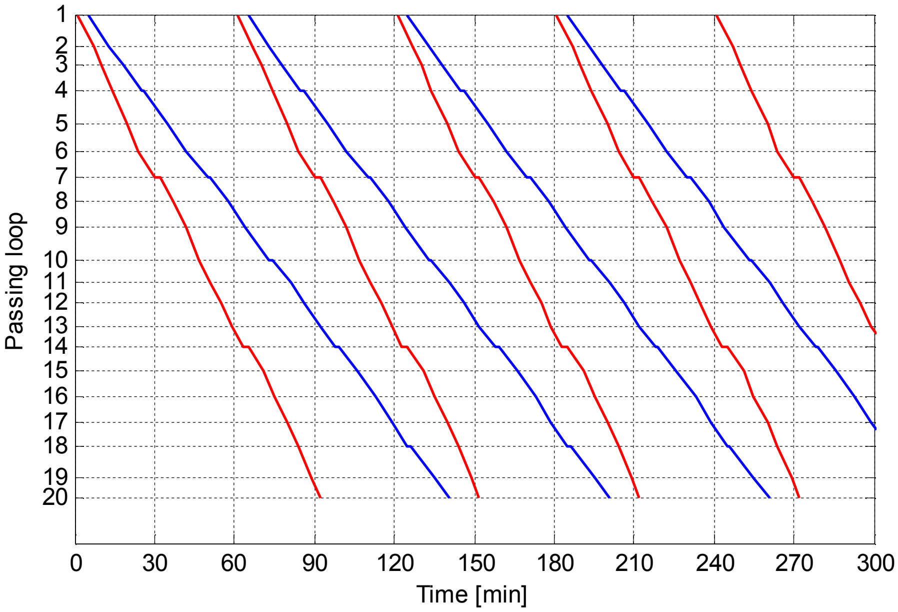
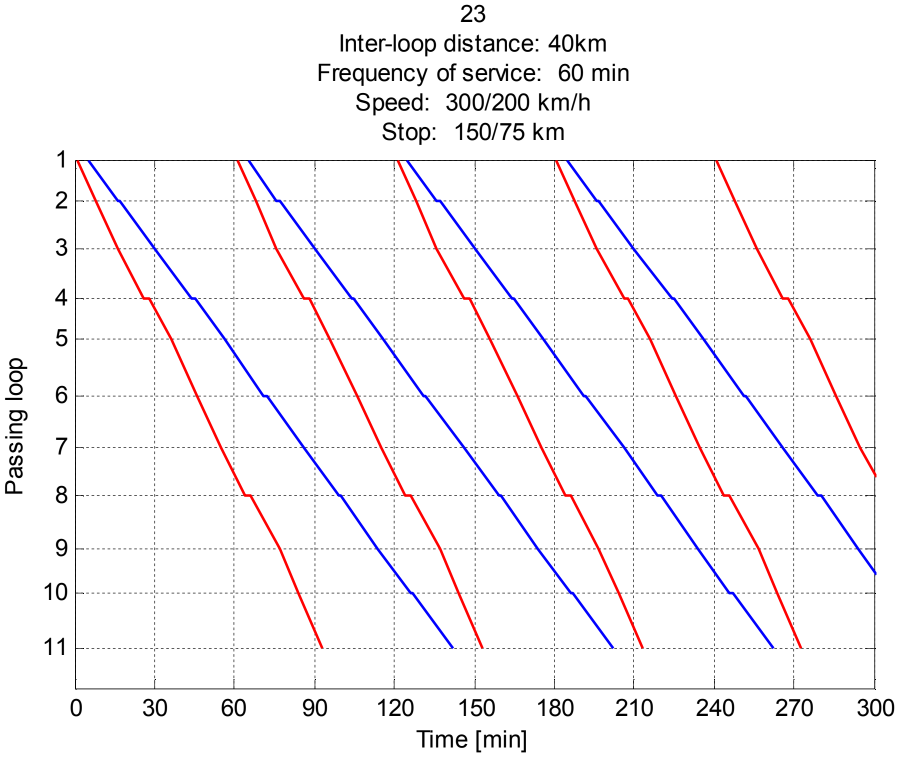
Time [min]



21
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 250/200 km/h
Stop: 150/75 km



22
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 150/75 km


23
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 150/75 km
Passing loop
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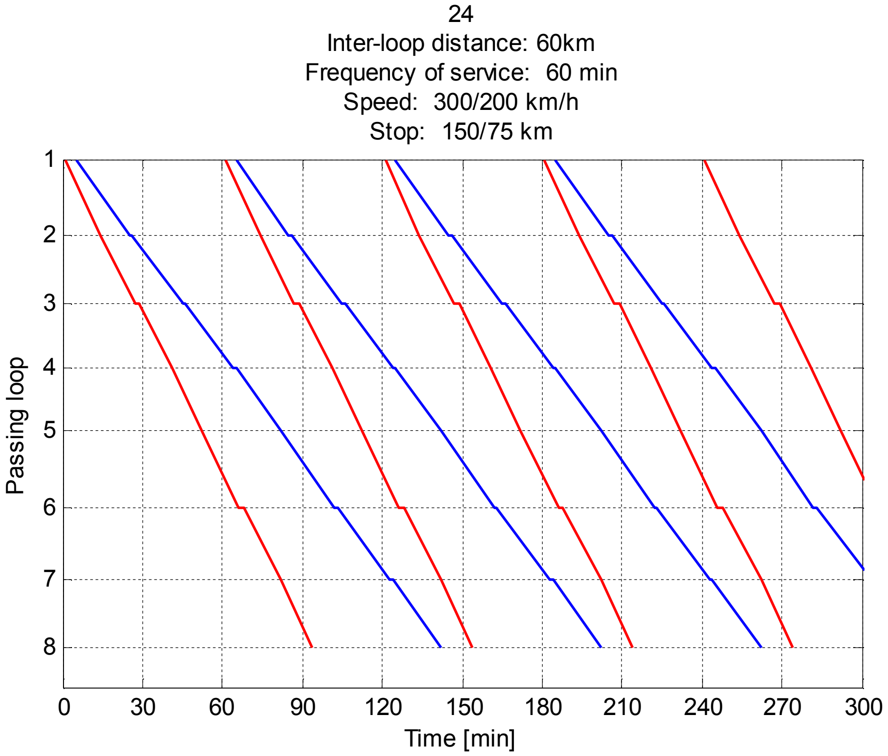
Time [min]


24
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 300/200 km/h
Stop: 150/75 km
Passing loop
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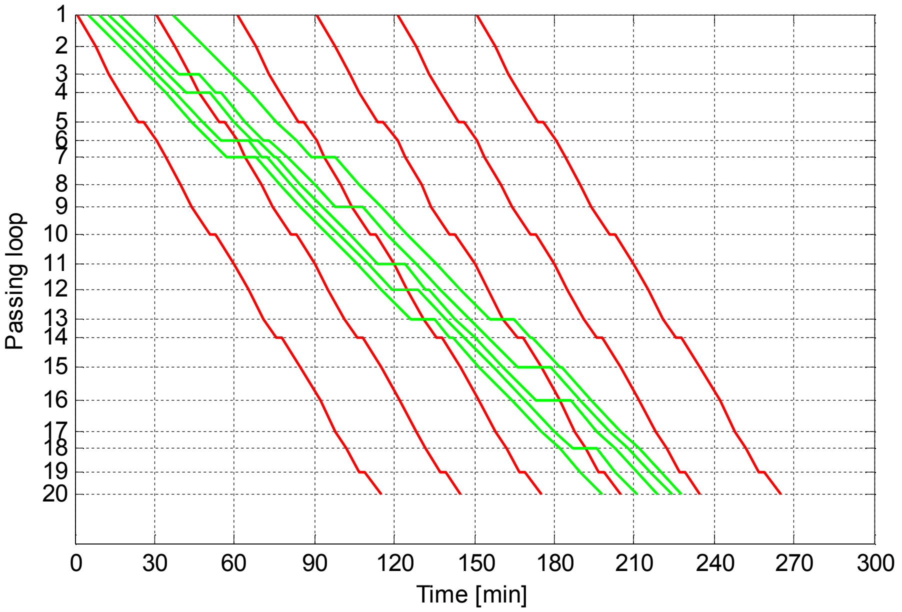
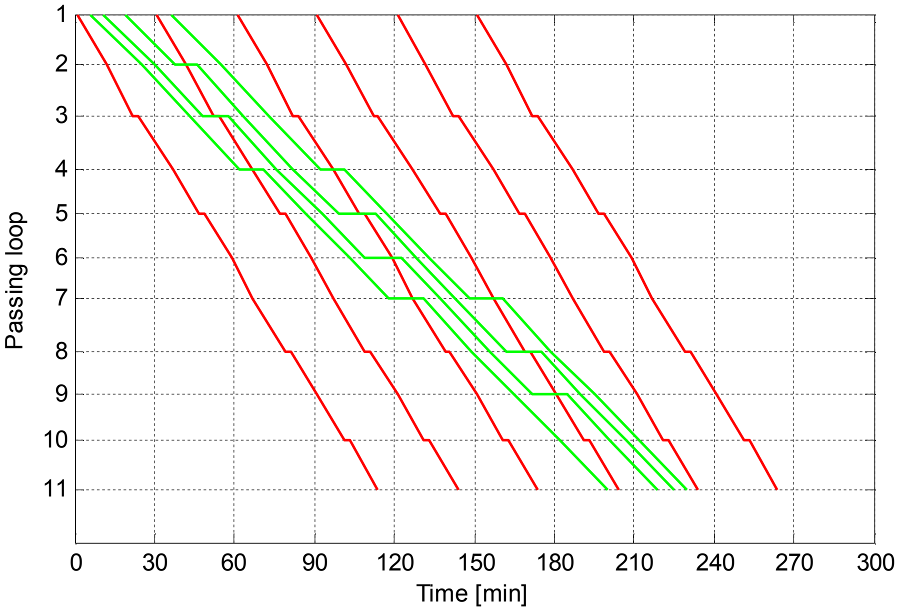
300
Time [min]

Appendix 3

Examples of timetables for different combinations of inter-loop distance, frequency of service, speeds and stop patterns. High-speed trains mixed with freight trains.

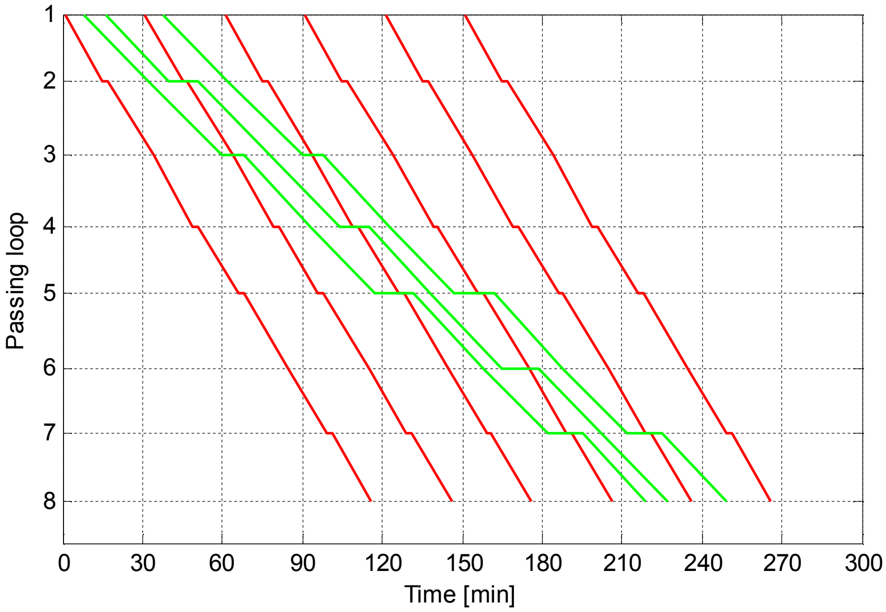


1
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 100 km

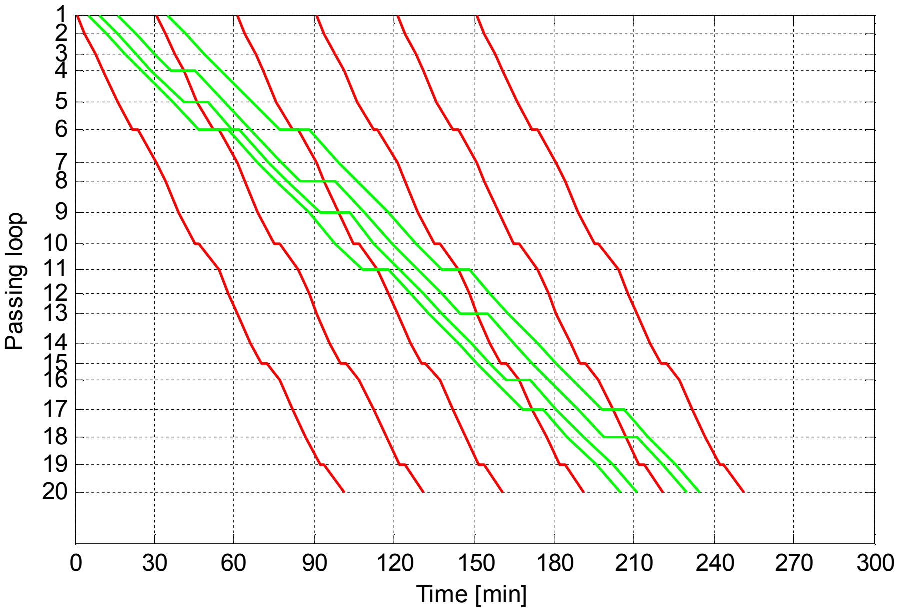


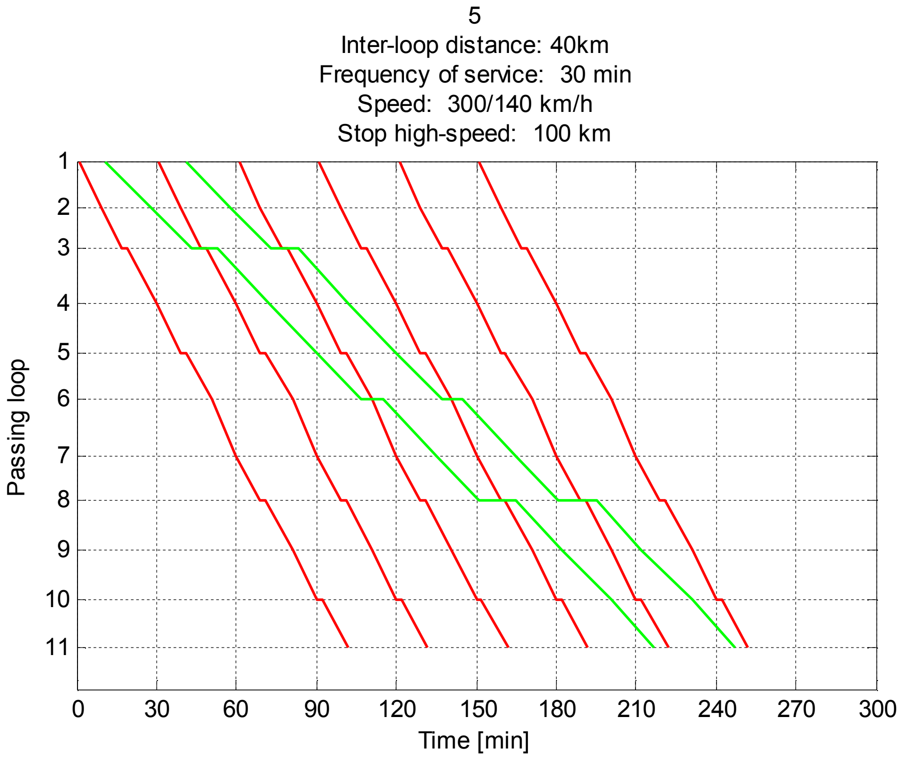
2
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 100 km

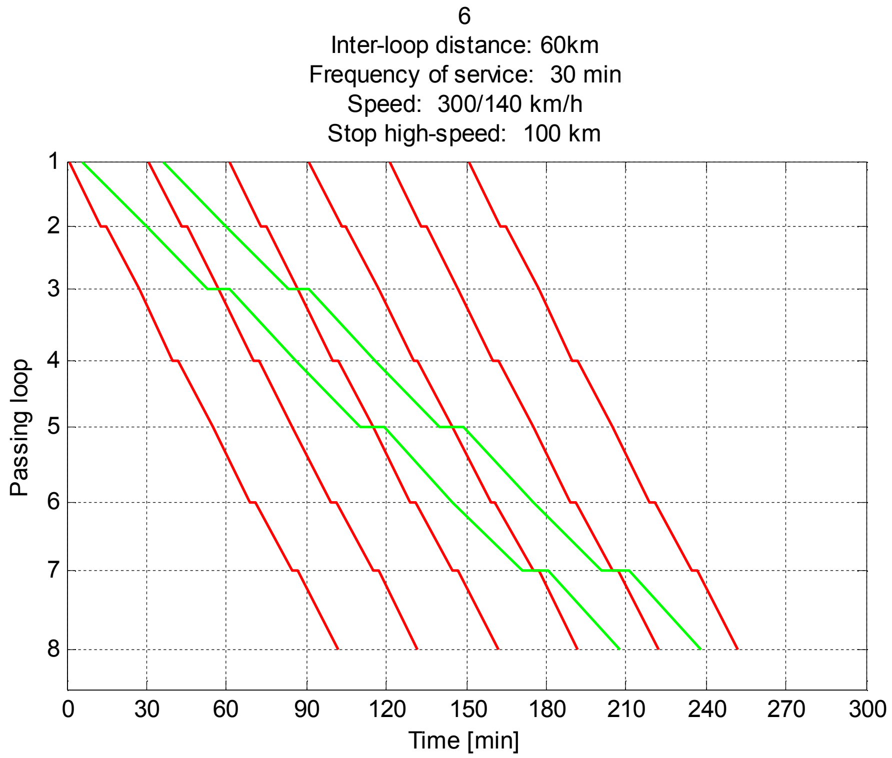
3
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 100 km

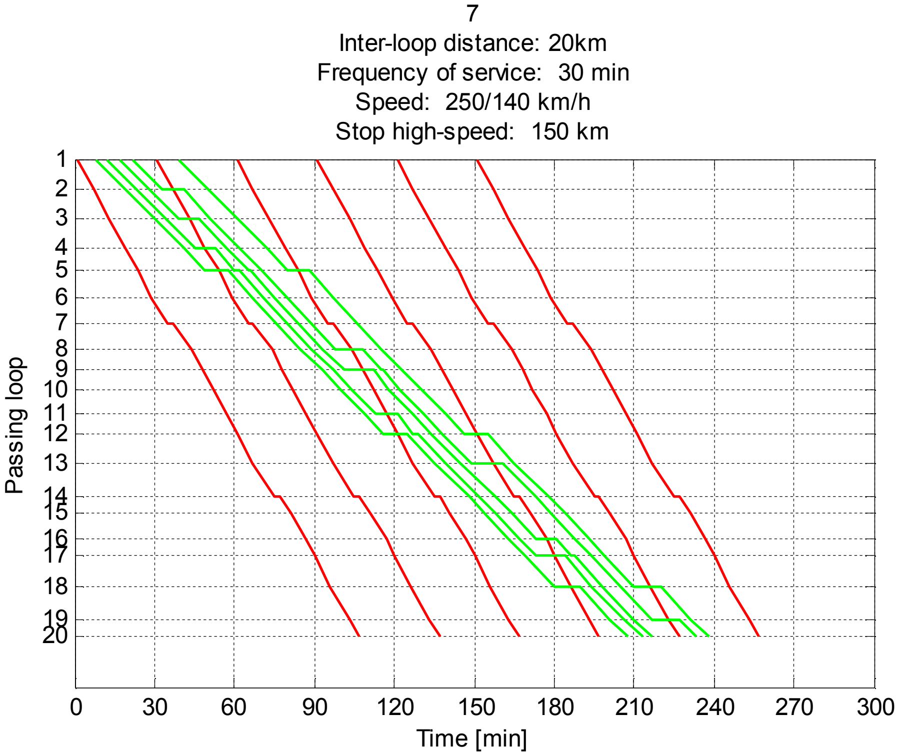


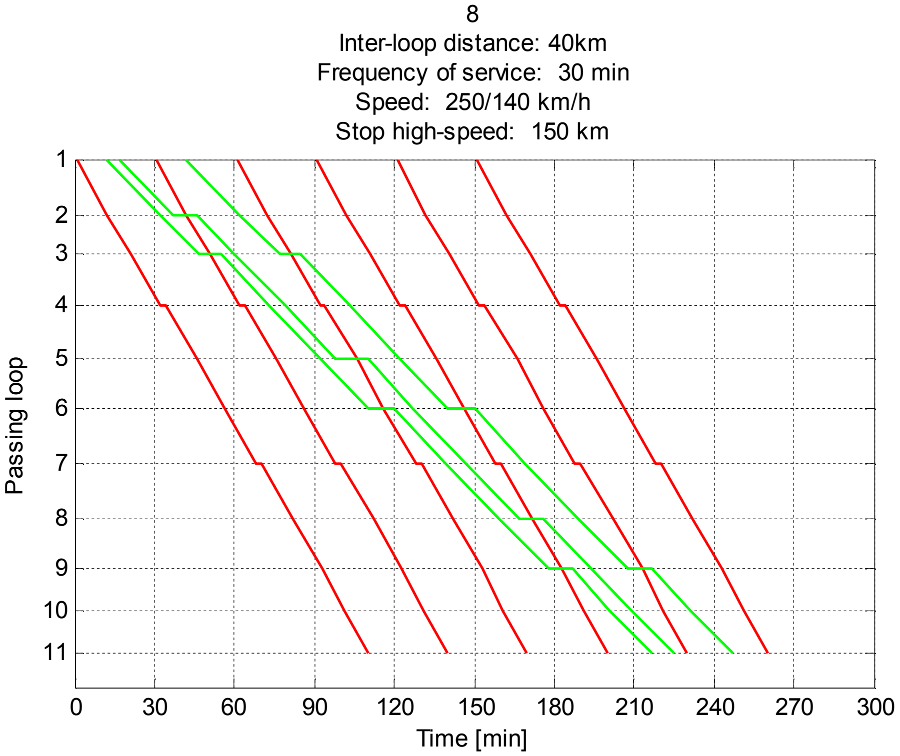
4
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 300/140 km/h
Stop high-speed: 100 km

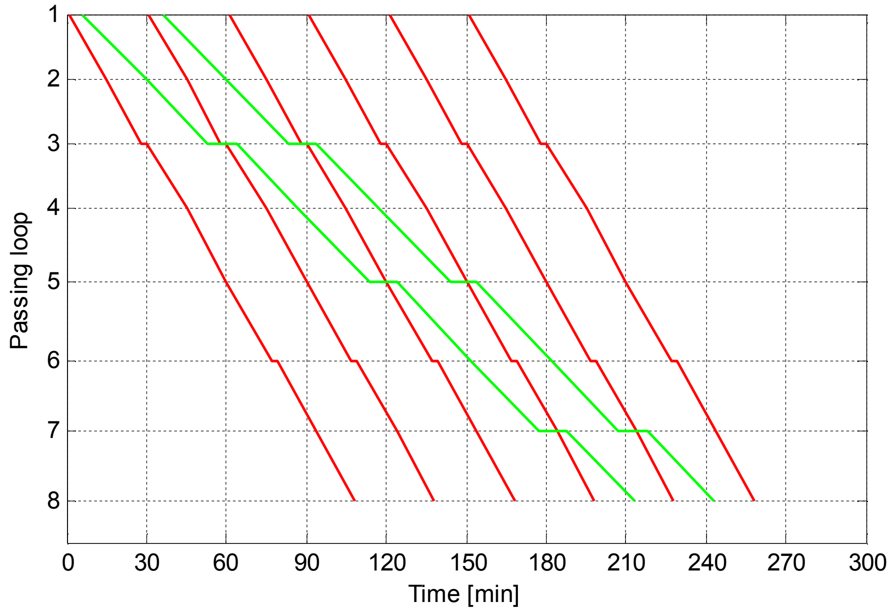



5
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 300/140 km/h
Stop high-speed: 100 km
Passing loop
1
2
3
4
5
6
7
8
9
10
11
Time [min]
0
30
60
90
120
150
180
210
240
270
300

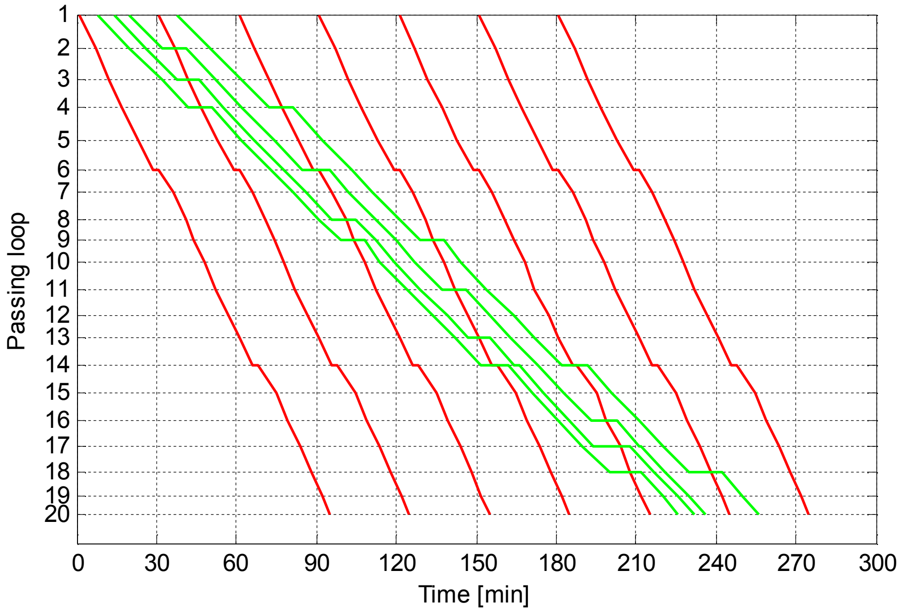

6
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 300/140 km/h
Stop high-speed: 100 km
Passing loop
1
2
3
4
5
6
7
8
Time [min]
0
30
60
90
120
150
180
210
240
270
300


7
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 150 km
Passing loop
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
30
60
90
120
150
180
210
240
270
300
Time [min]

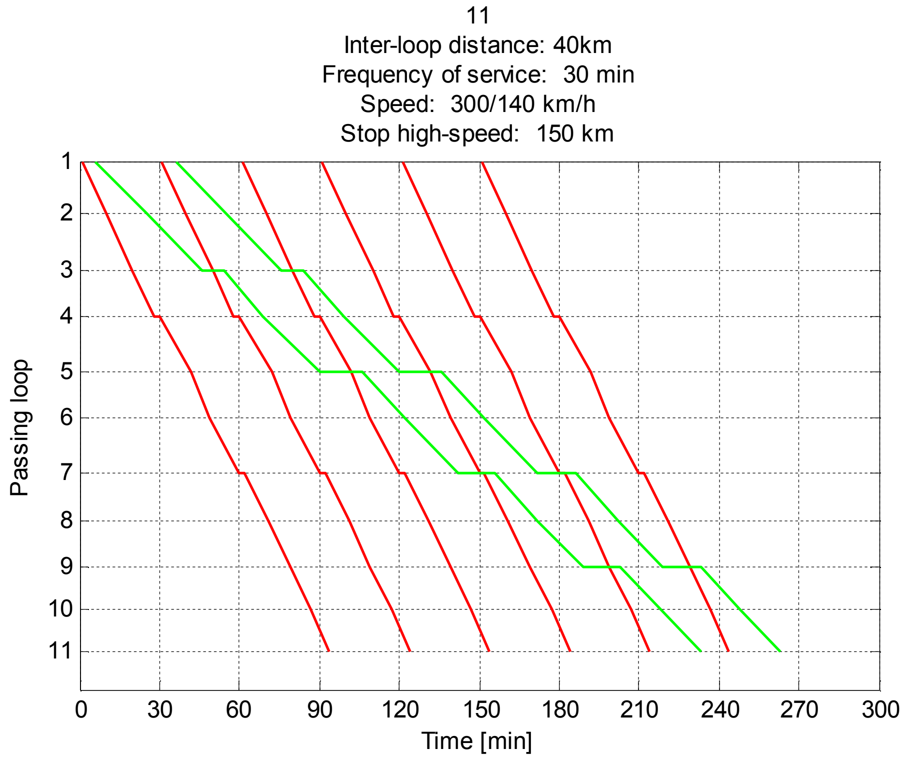

8
Inter-loop distance: 40km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 150 km
Passing loop
1
2
3
4
5
6
7
8
9
10
11
0
30
60
90
120
150
180
210
240
270
300
Time [min]

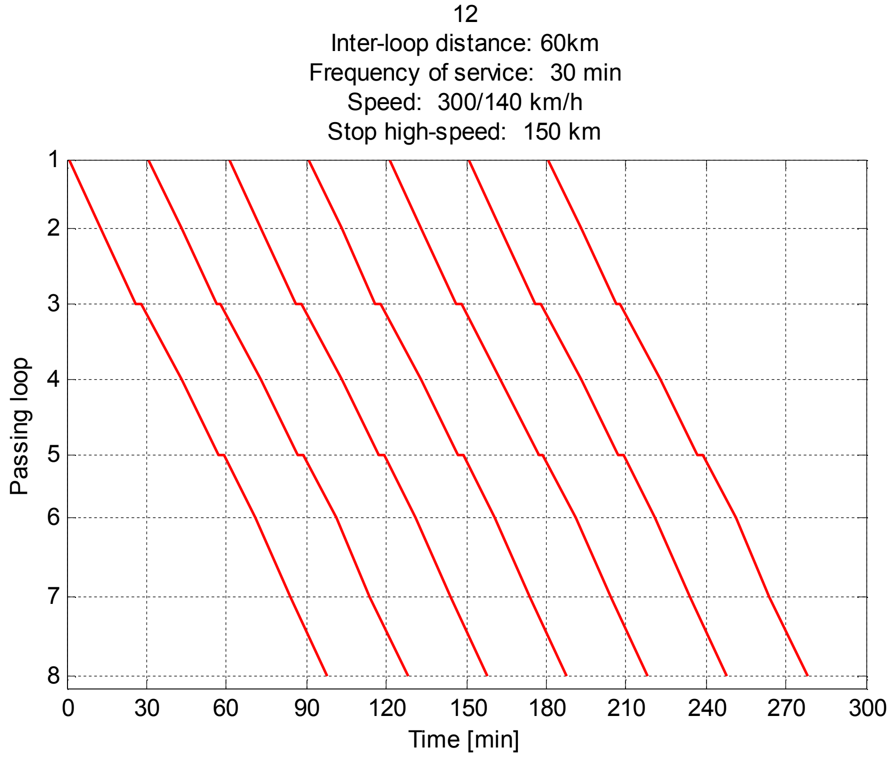


9
Inter-loop distance: 60km
Frequency of service: 30 min
Speed: 250/140 km/h
Stop high-speed: 150 km

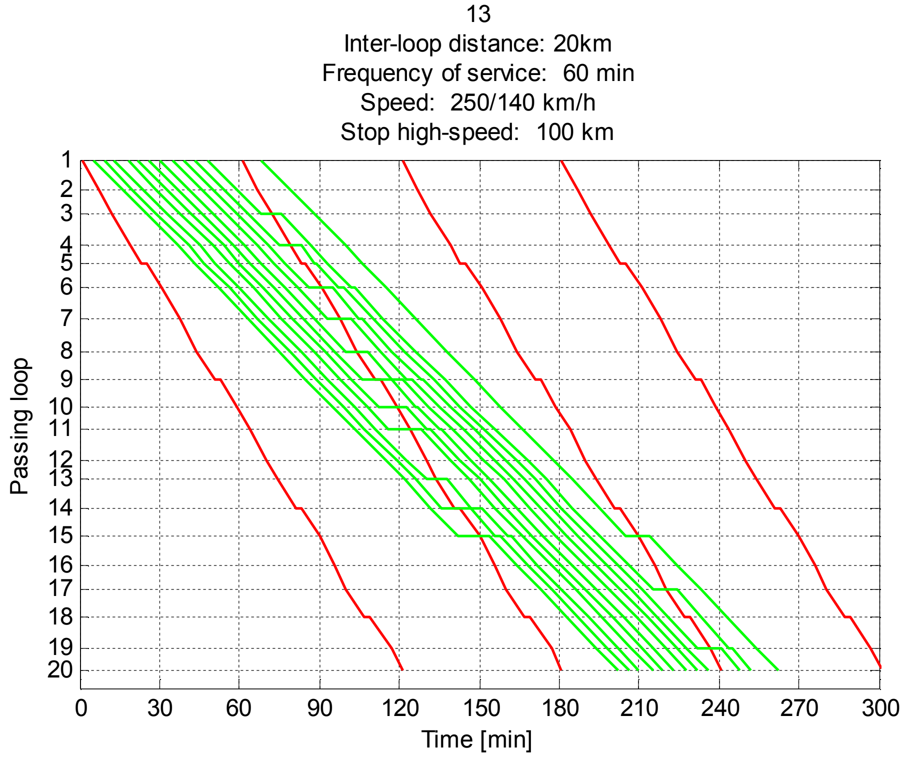


10
Inter-loop distance: 20km
Frequency of service: 30 min
Speed: 300/140 km/h
Stop high-speed: 150 km

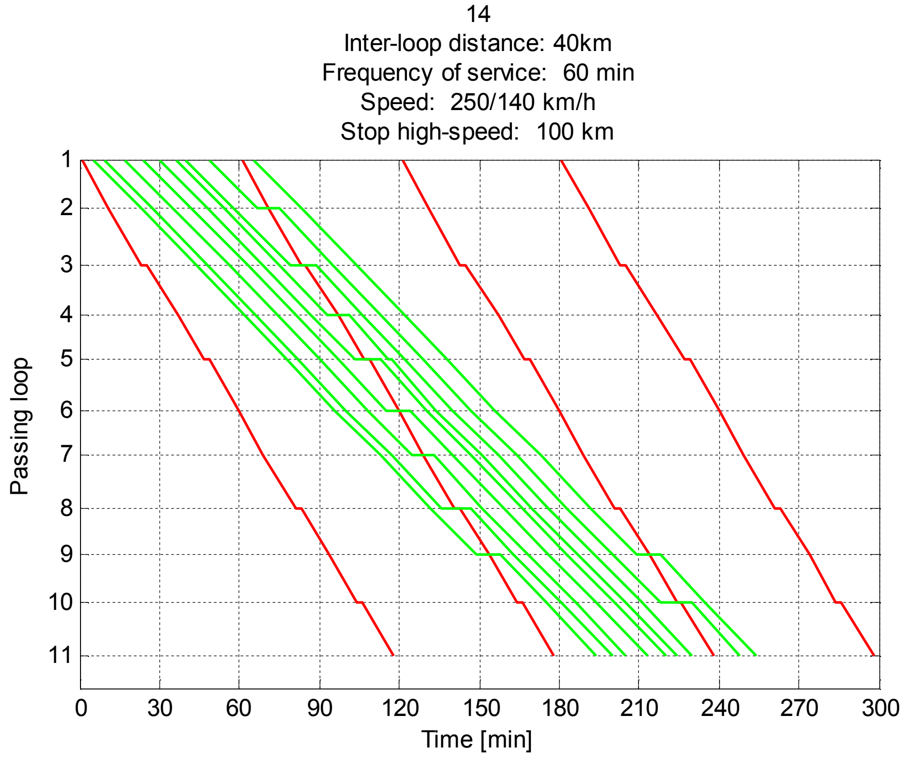




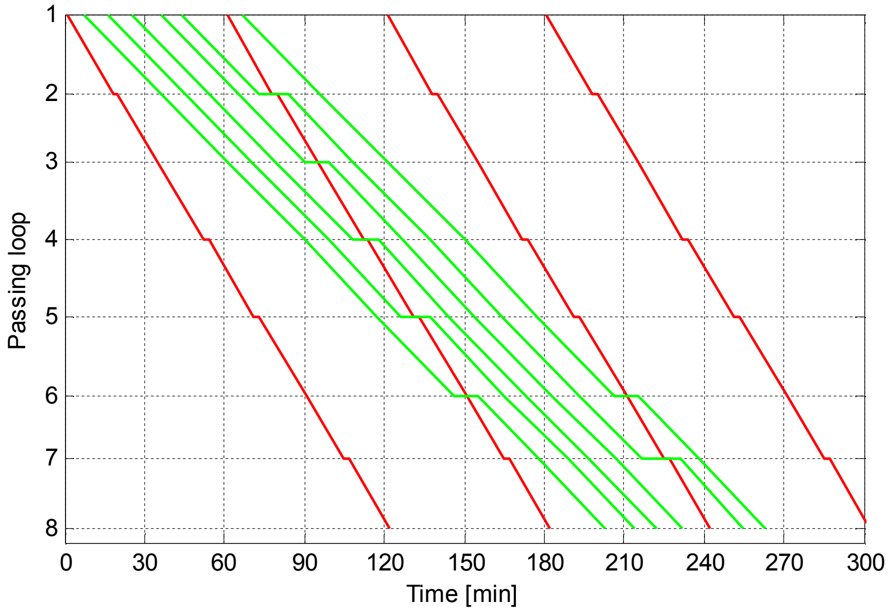
(No capacity for freight trains)

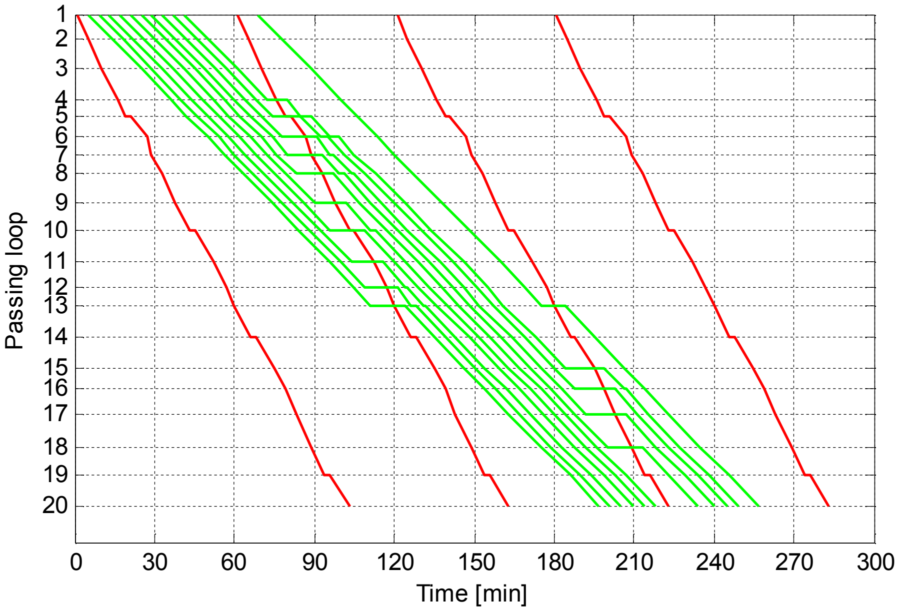


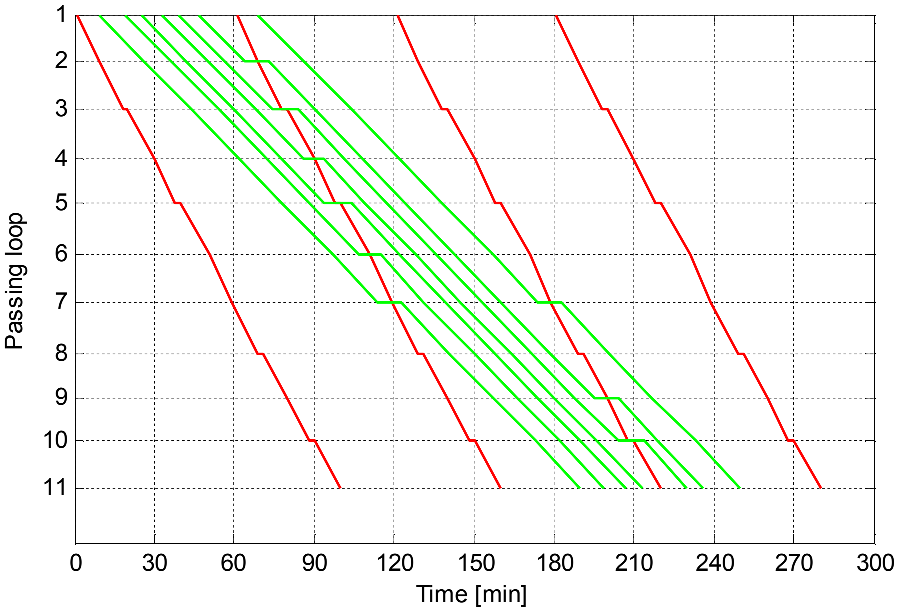
13
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 100 km

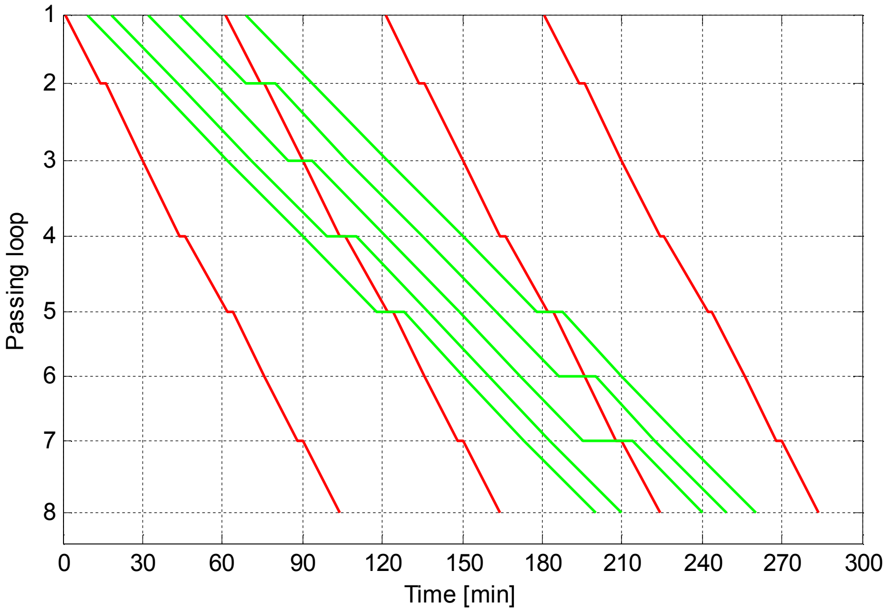


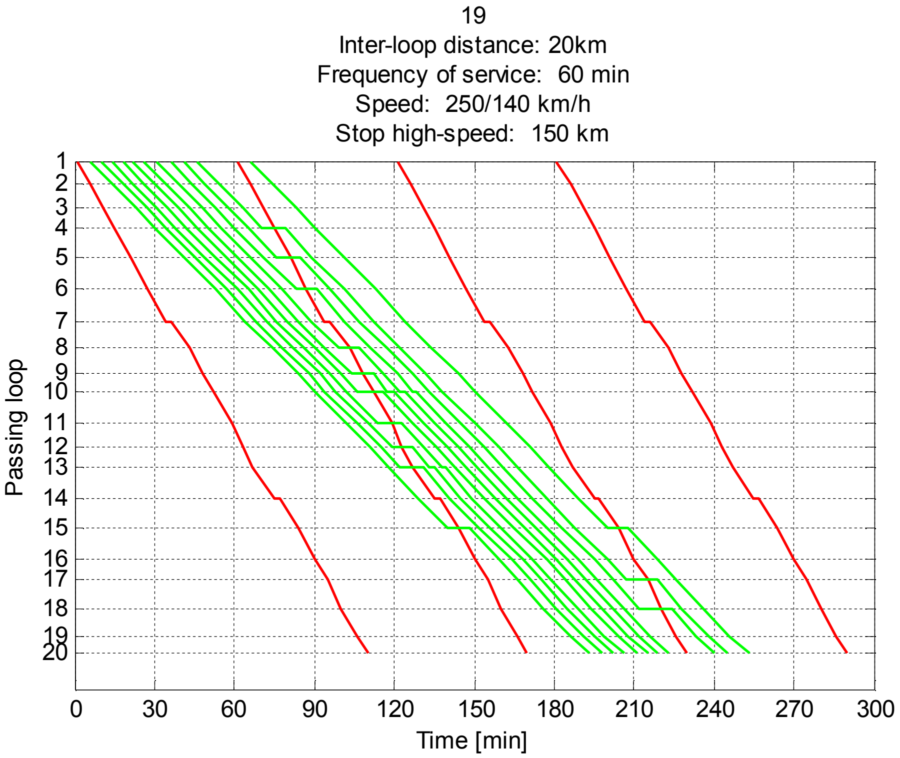
14
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 100 km


15
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 100 km


16
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 100 km


17
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 100 km


18
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 100 km


19
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 150 km
Passing loop
1
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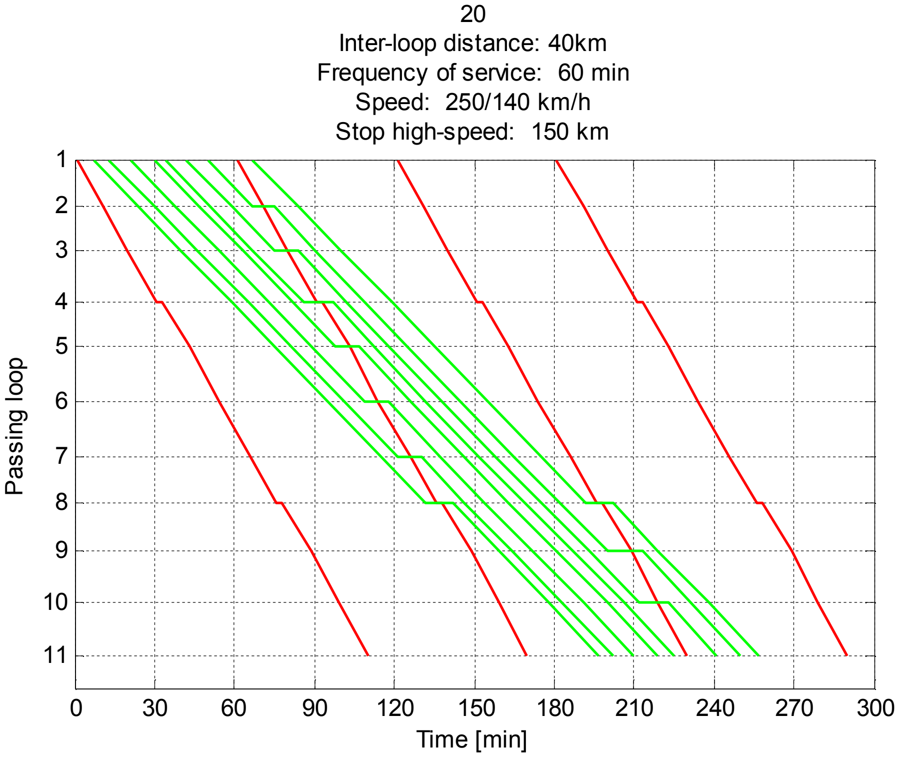
14
15
16
17
18
19
20
0
30
60
90
120
150
180
210
240
270
300
Time [min]


20
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 150 km
Passing loop
1
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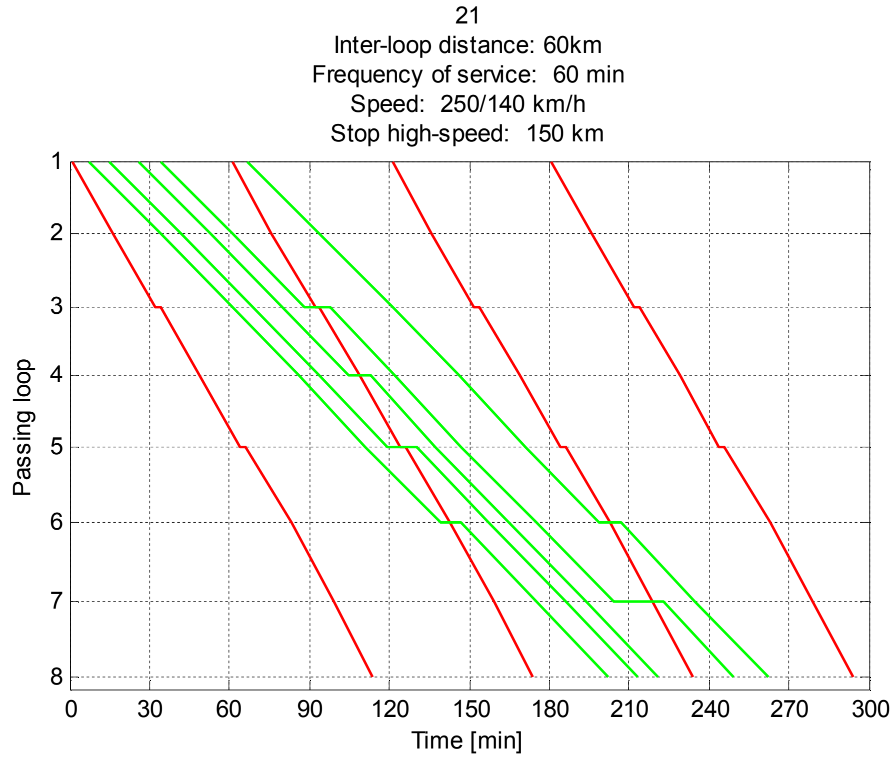
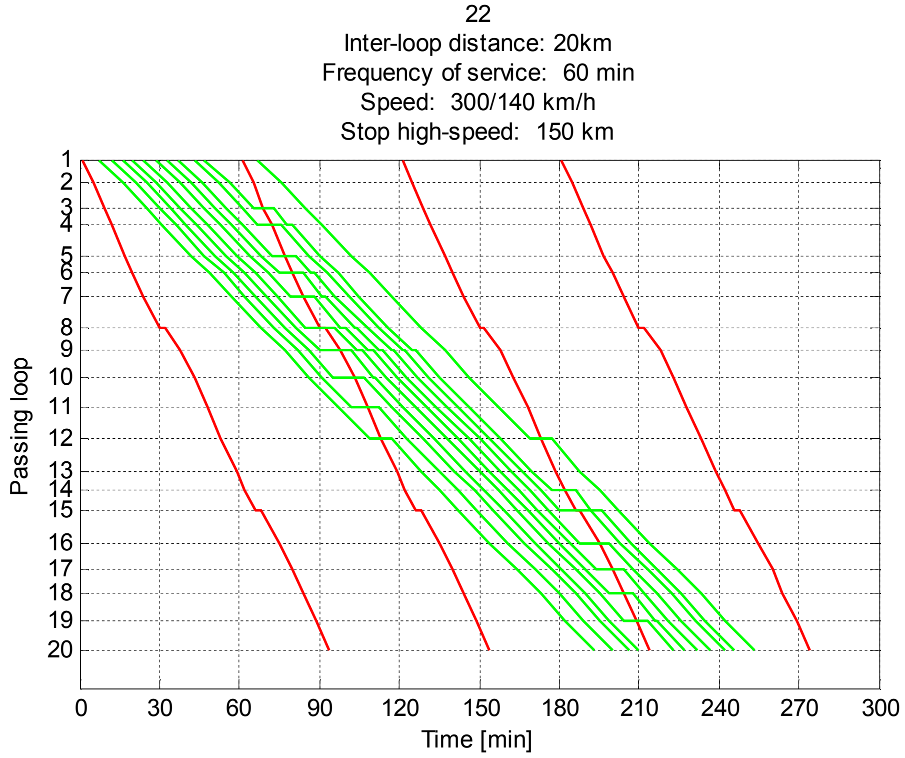
9
10
11
0
30
60
90
120
150
180
210
240
270
300
Time [min]


21
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 250/140 km/h
Stop high-speed: 150 km
Passing loop
1
2
3
4
5
6
7
8
0
30
60
90
120
150
180
210
240
270
300
Time [min]


22
Inter-loop distance: 20km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 150 km
Passing loop
1
2
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11
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15
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19
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0
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60
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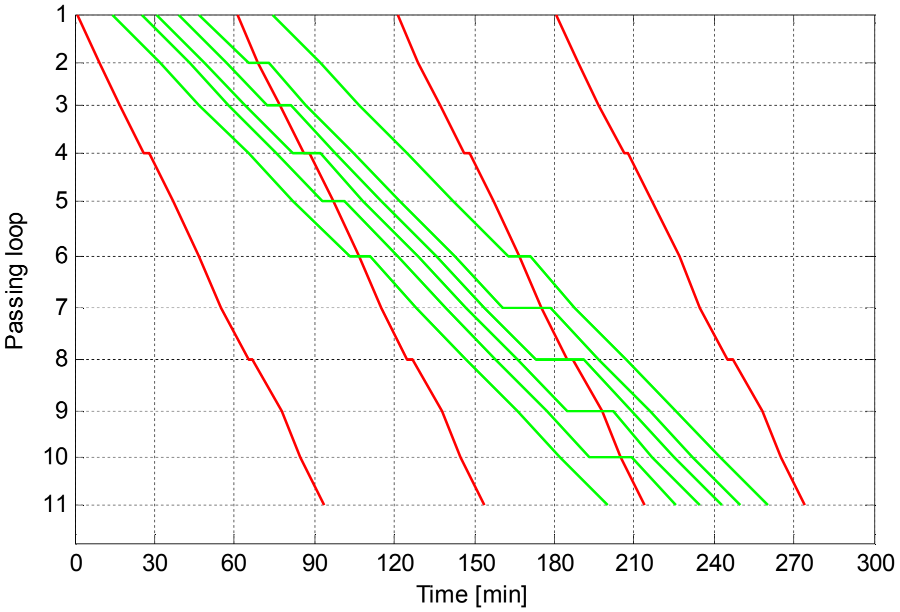
120
150
180
210
240
270
300
Time [min]

23
Inter-loop distance: 40km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 150 km



24
Inter-loop distance: 60km
Frequency of service: 60 min
Speed: 300/140 km/h
Stop high-speed: 150 km