Highspeed Railway Assessment - Rail Specific Planning and Development Analysis

APPENDIX 3

REPORT

Track loops

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Abstract

This report addresses the design and location of track loops. A track loop consists of two cross-overs where trains can shift from one line track to the other on a double-track railway line. The assignment mainly concerns the simple track loop although track loops play important roles also on major stations and passing loops.

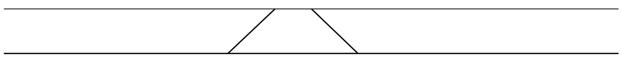


Figure A Simple track loop.

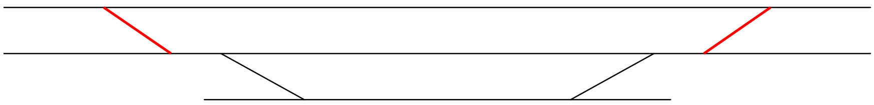


Figure B Combined passing and track loop. Track loop turnouts are marked with red.

Two design parameters are studied: the inter-loop distance and the turnout standard. The value of these parameters depends heavily on the capacity requirements. We assume the line to be operated by 4-6 trains/h (a mix of high-speed trains at 300 km/h (or 250 km/h) and regional trains at 200 km/h).

A reasonable requirement for the track loops is then that they shall manage this design capacity, so that cancelation of trains can be avoided. Requirements for low additional delays are assumed to be secondary. This is reasonable as long as the track loops are used only for redundancy and not used in the normal, scheduled operation.

This leads to the conclusion that the turnout standard is not a key factor. It is therefore reasonable to use the moderate **turnout standard of 100 km/h** (diverging track) for track loops that are used mainly for redundancy. One exception from this recommendation is one-sided passing loops where the track loop turnouts can be given a higher standard to ensure time and capacity efficient overtakings (red turnouts in figure B). In this case we recommend a standard of 130 km/h to harmonize with the passing loop turnouts.

The inter-loop distance is a more important design factor. A capacity requirement of 4-6 trains/h and direction means that **an inter-loop distance of 18-20 km is needed**. This distance makes it possible to operate 4 trains/h and direction in one-by-one operation and at least 6 trains/h and direction in bunched operation with bunches of two trains.

The expected additional delay will then be 10-12 minutes/train. This delay level applies for improvised single-track operation and can be significantly reduced if the timetable is adjusted for single-track operation imposed by planned maintenance works etc.

Introduction and background

Track loops are cross-overs that connect the two line tracks on a double-track railway line. They are usually located at major stations/junctions, at passing loops (minor stations) or just on the line as simple “crosses”.

At major stations, junctions and passing loops the track loops provide access to the station tracks from both line tracks. This increases flexibility and capacity of the station/loop.

This report does not primarily concerns this function of the track loops. Instead focus will be on the use of these loops to maintain traffic during maintenance work, failures etc that cause closure of one of the two line tracks. This implies a temporary single-track operation between two adjacent track loops.

The task is to find a suitable distance between the track loops as well as a recommendation of speed level in the turnouts. The evaluation will be based on expected frequency of traffic and capacity for temporary single-track sections.

Track loop design and loop spacing

The track loop is a rather simple design with four turnouts positioned so that they form two cross-overs that allow trains to shift from one main track to the other. It is feasible to distinguish between two types that occur on double-track lines outside major stations:

- Simple track loop.
- Combined passing and track loop.

A simple track loop can only be used to switch from one track to the other, whereas a combined loop also gives access to the passing loop from the outer track.

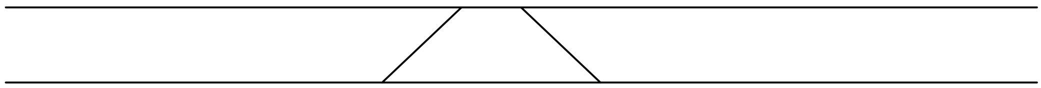


Figure 1 Simple track loop.

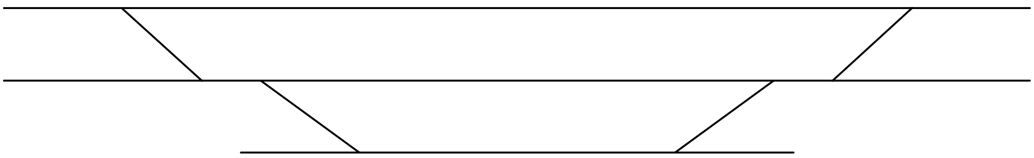


Figure 2 Combined passing and track loop.

The major design parameter for a track loop is the permissible speed for the diverging track in the turnouts. This turnout standard affects the delay caused to the trains when they are forced to switch tracks. To some extent the turnout standard also affects the capacity for single-track operation through its influence on the run time between two adjacent track loops. Two turnout standards are tested within this assignment: 100 km/h and 130 km/h, see section about "Independent factors" for details.

A track loop does not work on its own. In most cases two or more track loops are used during special operational modes such as temporary single-track operation, parallel operation etc. This means that the track loops cannot be designed individually. The inter-loop distance is a factor of great interest.

Figure 3 shows a typical example with combined passing and track loops and simple track loops in-between them. A typical distance between track loops is 10-20 km and the choice of distance depends mainly on capacity requirements as will be shown later.

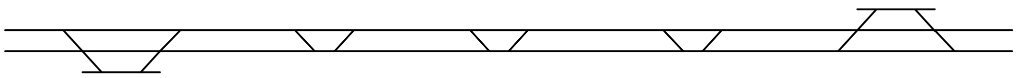


Figure 3 System of track loops.

Operational situations where track loops are used

Track loops are used mainly in two different situations:

- Temporary single-track operation.
- Parallel operation.

Figure 4 shows a typical single-track operation where one of the line tracks is blocked. Reasons for such blockage could be vehicle failure, track or signal failure, planned maintenance etc. In such cases it is often feasible to let all traffic pass on the other, still operational track. In the case illustrated in figure 4 train A is dispatched from its original track to the "opposing track" between the two adjacent track loops.

Depending on the timetable, actual delays and the time needed for train A to traverse the distance between the loops, a number of trains will form a queue waiting to access the single-track section in the other direction, illustrated by train B and C.

The main aim for the system designer is to design the track loops and the distance between them so that the capacity for this kind of operation is high enough. This is done in this assignment through run time calculations.

A secondary aim is to design the system so that additional delay caused to the trains in this kind of operation becomes reasonable. This delay consists of three major parts: braking, waiting and passing (acceleration included) the single-track section. These parts are also estimated within this assignment. However, the very important waiting time is strongly dependent on the timetable and capacity utilisation. This means that more accurate estimates must be done for each timetable case.

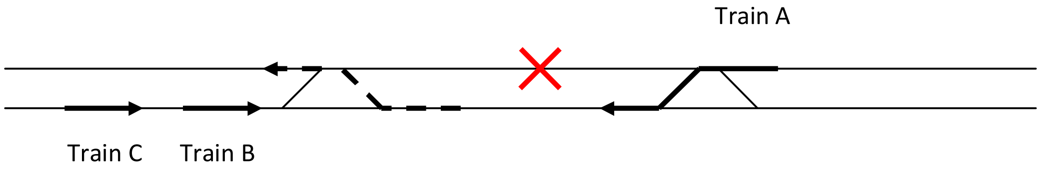


Figure 4 Track loops used for temporary single-track operation.

The other situation where track loops are used is the so called parallel operation. This kind of operation is common during off-peak hours, e.g. night time etc, when the traffic is sparse and not evenly distributed over time. Due to the low capacity utilisation during these circumstances, it is possible to use the line tracks for "flying overtakings".

This means that the faster train is scheduled on the normal track, whereas a track loop is used to switch the slower train to the opposing track. In most cases another track loop is used, when the overtaking is completed, to switch the slower train back to the normal track in order to manage crossings further downstream.

The procedure is illustrated in figure 5. The faster train is following a slower one. A track loop is used to switch the slower train to the opposing track so that a flying overtaking can be performed. A second track loop is used to switch the slower train back to its normal track after the overtaking is completed and before the next crossing is to take place.

This type of operation should be regarded as special use of spare capacity and usually it is not taken into account when the infrastructure is designed. The reason for this is that this operation requires long distances (several inter-loop distances) and long periods of time that are free from opposing traffic.

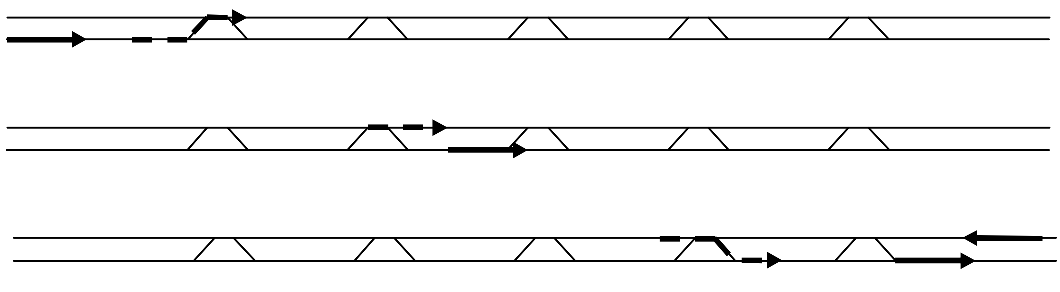


Figure 5 Sequence showing track loops used for parallel operation.

Measures of performance

The capacity (throughput), measured in trains/h that could be run in temporary single-track operation between two adjacent track loops, is chosen as the main measure of performance. It is desirable that the scheduled traffic can be led through this type of single-track section without any cancelled trains.

A rough estimate of the additional delay for each train in such a temporary single-track operation is chosen as complementary measure of performance. This delay is calculated for two levels of utilisation: max utilisation, corresponding to the maximum capacity and an optimal timetable that is adjusted and free of conflicts in the single-track section.

Independent factors

Four independent factors are studied within this assignment:

- Inter-loop distance (loop spacing).
- Turnout speed (diverging track).
- Maximum speed (vehicle type).
- Bunch size

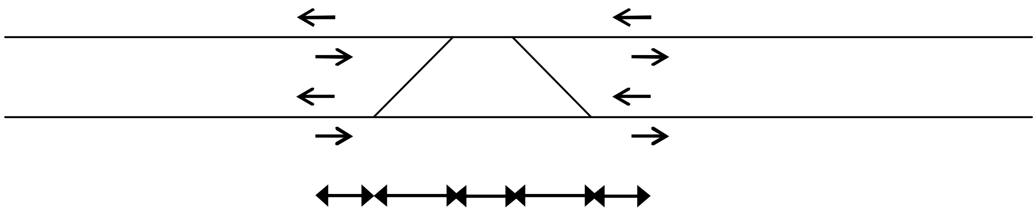
The **inter-loop distance** affects both capacity and delay times directly. A longer distance means longer run times which in turn imply lower capacity and more waiting time for clearance and direction change. Typical inter-loop distances on conventional lines are 10-15 km.

Due to higher speeds and higher availability in this kind of railway lines, longer distances might be accepted. For these reasons 10, 20 and 30 km inter-loop distance are chosen for evaluation in this assignment. The distance is here defined as the length between the entrance signals, the outer signal pair (up- and down track) in figure 6, of two adjacent track loops. The length of the track loop is thus not included in the distance.

The **speed restriction for the diverging track in turnouts** forces switching trains to slow down before a track loop, which extend the traversing time between the track loops. This results in lower capacity and more delay. The speed restriction also implies greater additional delay compared to “normal” double track operation without track switching.

Two different permissible speeds at turnouts (diverging track) are evaluated: 100 km/h and 130 km/h. A higher standard, e.g. 160 km/h, could also be considered, but our experience from this kind of operation is that trains are queuing before the entrance track loop, which means that they start from a standstill and cannot utilise the high standard in the turnouts of the entrance track loop. Furthermore, only half of the trains are run through diverging tracks where the speed restrictions apply. This fact also limits the total effect of a high turnout standard.

Different turnout standard imply different loop lengths, as shown in figure 6. The main signals, where the trains stop to wait for clearance are here located 100 m from the turnout which gives a proper overlap for the signalling system. Using these measurement chains the total loop lengths ends at 516 m and 650 m respectively.



Turnout	Distances [m]					Loop length [m]
100 km/h	100	148	20	148	100	516
130 km/h	"	215	"	215	"	650

Figure 6 Length of track loop with different turnout standard. Main signals marked with simple arrows beside the tracks.

The **maximum speed** of the trains also affects capacity and additional delay. The maximum speed is here represented by two vehicle types: one high speed train operated at 300 km/h and one regional train operated at 200 km/h. The use of different vehicles also includes slightly different acceleration characteristics. Data for the two vehicles are shown in appendix 1.

Bunched operation means that more than one train is sent after each other in the same direction, before the direction is changed and another bunch of trains is sent in the opposite direction. This procedure increases capacity since the direction change, i.e. emptying of the operational line track, is time and capacity consuming. The **bunch size**, i.e. the number of trains sent at a time, is therefore a factor of importance for the capacity.

Bunched operation is a necessity on heavily utilised railway lines such as commuter lines etc. Less utilised lines may be operated with smaller bunches or even with one train at a time. Bunch sizes of one and two trains are used in this assignment to show how small bunches affect capacity compared to single-train operation.

The bunch size is also a commercial issue since the increase in capacity has to be paid for with extended waiting times, i.e. delays, for the trains. This is the main reason why only small bunches of two trains are evaluated within this assignment.

Constants and other assumptions

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

Characteristics of the signalling system. The signalling system is assumed to be of ERTMS level 2 type. This means that driving permissions are continuously updated, but train routes are only released at block signals (no moving block). The interlocking time, i.e. the time needed to release a route, set the next route, transmission to the following train and reaction of its driver, is set to 15 seconds. Five seconds are added to this time when switches are to be changed in setting the new route.

The **block lengths** between track loops are set to 1 000 m. This a normal length that gives good releasing properties, close to that of moving blocks, for high-speed trains.

The **overlap** is set to 100 m. The overlap is the security distance beyond a signal that has to be cleared before a train route can be set to the signal.

A **buffer time** of 30 seconds is used to take the driver behaviour into account, see Berg von Linde (2002) for a reference. This is necessary since most drivers do not drive as close as possible to the preceding train since this forces them to accelerate and brake alternately as higher speed requires a longer distance to the preceding train (see figure 8 for an example).

Gradient. The entire line is assumed to be horizontal.

Maximum speed. The maximum line speed is constant and equal to the maximum speed of the analyzed vehicle.

Model description

The signalling system together with the train movements are the key parts that need to be modelled to answer the raised questions about capacity and additional delay in temporary single-track operation.

It is possible to perform this kind of study in a commercial simulation tool. However, the large number of variants that need to be evaluated calls for more time efficient methods. The fact that the train sequence is predefined makes it possible to perform deterministic analyses where the dispatching algorithms included in the simulation tools are not needed.

A simple model for the train movements and the signalling system was constructed for this assignment. The model distinguishes between two operational cases of special interest:

- Maximum capacity operation.
- Minimum additional delay operation.

Analysis of the *maximum capacity operation* is essential to answer the main question regarding design for a required level of capacity. This kind of operation is also very common in real life when temporary single-track operation is imposed by accidents, failures etc. In such cases all uncertainties and time losses associated with the shift from the scheduled (normal) double-track operation to temporary single-track operation mean that several trains come to a standstill before the single-track operation is established.

For this reason it is reasonable to assume all trains to brake and stop before the entrance track loop and wait for clearance before continuing. The model then has to capture the interaction with the signalling system during the run through and between the track loops. Both speed restrictions imposed by preceding trains and turnouts has to be modelled. Set and release times for each block section have to be modelled with regard to train runs, interlocking times etc.

Figure 7 shows an example of maximum capacity operation. The inter-loop distance is here 20 km, which means that the entrance signals from which the first trains start are located 21,03 km apart since two loop lengths are included in this distance. Also note that the second train in each direction starts from a position one km behind the starting point of the first train. This distance corresponds to the length of one block section. Blue trains use their original track and do not suffer from the speed restrictions at turnouts. Red trains switch track both at their entrance track loop (loop 2) and at their exit track loop (loop 1). In both cases the turnouts restrict the speed. The resulting capacity can be read from the cycle time, i.e. ca 1 080 seconds in this case. This gives a total capacity of 2*3 600/1080 = 6.6 trains/h and direction.

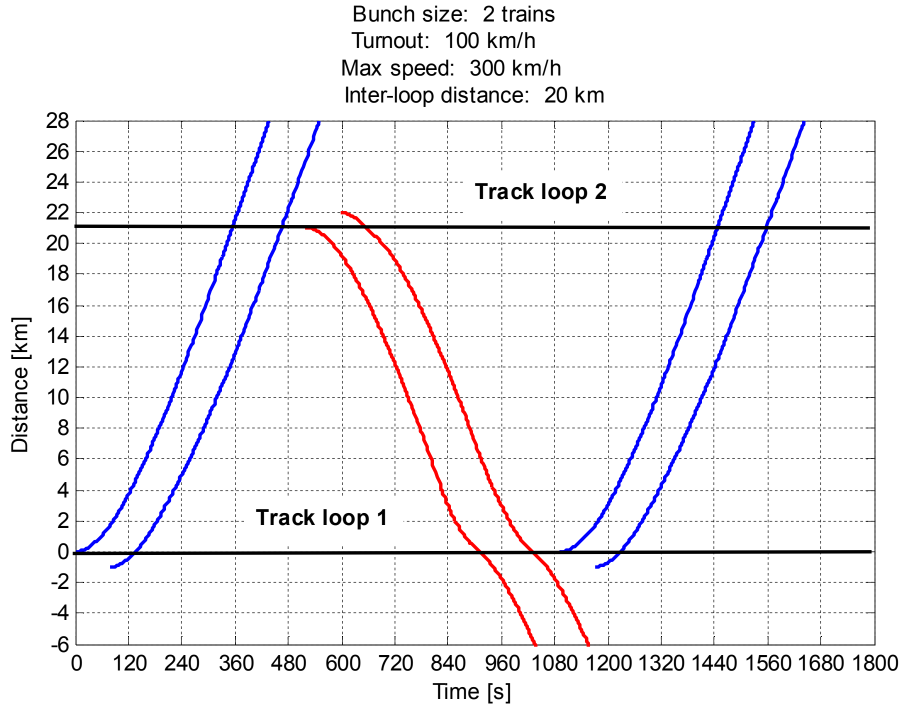


Figure 7 Graphical timetable for bunched single-track operation between two track loops.

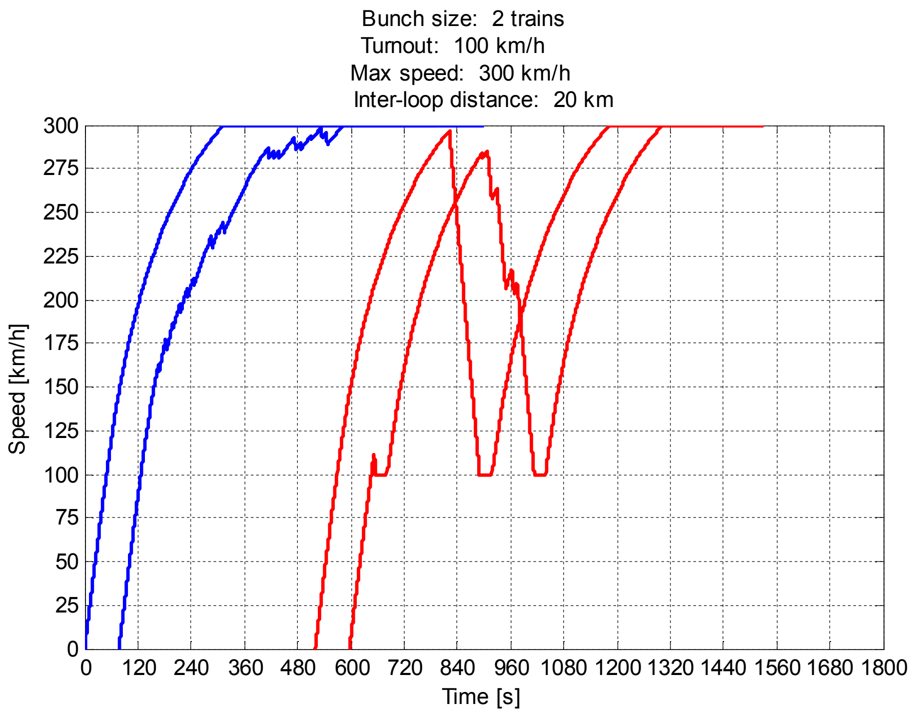


Figure 8 Speed-time diagram bunched single-track operation between two track loops.

Figure 8 shows some more model details. Please note that the starting times of the trains correspond to them shown in the previous graphical timetable (figure 7). Once more it is possible to see that blue trains do not need to brake for any turnouts. Instead, the second blue train has to brake for the preceding train, since a longer headway distance is needed when the speed grows.

The red trains have to wait for both blue trains to cross, before they start. The first of these trains waits at the entrance signal of track loop 2 (figure 7). It is so close to the turnouts that these do not restrict its acceleration course. The 20 km inter-loop distance makes it possible to accelerate almost all way to 300 km/h (21.8 km would be needed for complete acceleration plus deceleration) before it has to brake for the turnout in the farther track loop.

The second red train follows the first one. Since it starts one block section before the entrance signal (1 000 m) it needs to brake for the turnouts in the entrance track loop. Despite this braking it comes a little too close to the preceding train and needs to brake a little extra on its way towards the farther track loop.

The analysis of *minimum additional delay* is in some sense easier to perform. In this case the trains are assumed to arrive to the track loops in such a sequence and with such time distances that they do not affect each other. This means that only the track loops cause delay. Furthermore, this delay is only caused to half of the trains, since the trains that do not need to switch tracks can pass the single-track section without any influence.

Results

The constructed model for single-track operation between track loops was first applied on the 24 variants that result from the chosen factors (inter-loop distance, turnout speed, maximum speed and bunch size) and factor levels. Detailed results for all variants with graphical timetables and speed diagrams are shown in appendix 2.

Focus was kept on maximum capacity, since the main purpose with track loops is to maintain capacity rather than running times. The screening process, containing all 24 variants, was followed up by a more detailed study of the impact of inter-loop distance.

Maximum capacity operation

The maximum capacity operation is a case of special interest since it shows the limit where the train traffic has to be reduced through cancelations in order to avoid growing queues and “traffic jam” on the railway line. This capacity level can be analytically determined independently of the timetable. More detailed studies of delay etc that follows on temporary single-track operations requires much more knowledge or assumptions about the arrival process of the trains, i.e. timetable, entry delays etc.

Figure 9 shows capacity for each of the 24 variants. It is seen that the bunch size and the inter-loop distance are the most important factors. The capacity increase for bunched operation is 45-75%. Bunching has greatest effect when inter-loop distance is long (30 km) and maximum speed is low (200 km/h). A short inter-loop distance and fast trains makes bunching much less beneficial.

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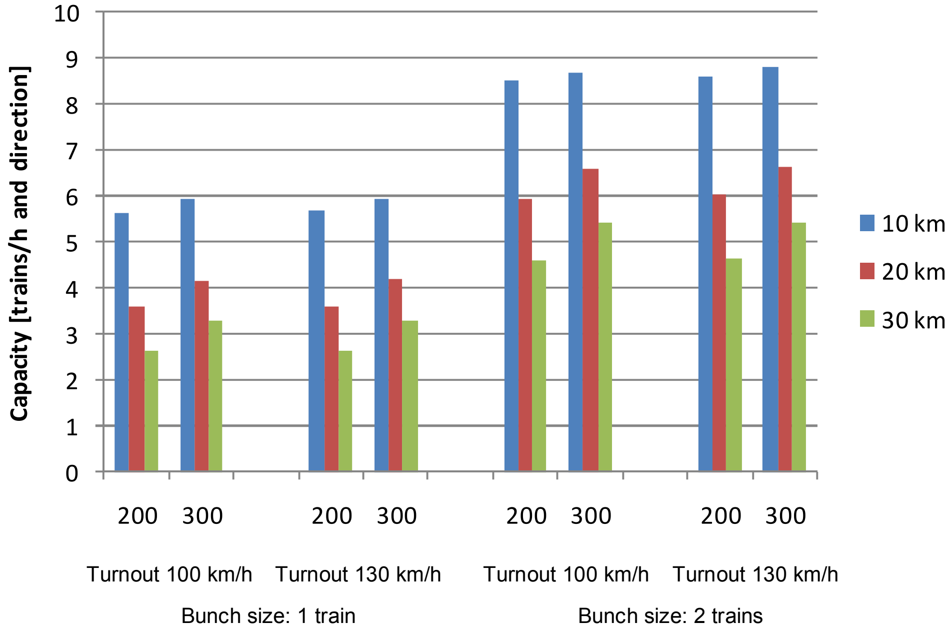


Figure 9 Maximum capacity for temporary single-track operation. Each bar shows the number of trains per hour that can be operated in each direction given maximum speed (200 or 300 km/h), turnout standard (100 or 130 km/h), bunch size (1 or 2 trains at a time) and a specified inter-loop distance (10, 20 or 30 km).

The inter-loop distance is more important for the slower trains. A change from 30 to 10 km inter-loop distance means a capacity increase of 110 % for traffic at 200 km/h but only 60 % for traffic at 300 km/h.

The turnout speed seems to be a factor with minor impact on capacity. This is reasonable since:

- Only half of the trains suffer from speed restrictions in turnouts.
- The speed restrictions (for restricted trains) almost only apply at the exit track loop since the restriction at the entrance loop lies over the acceleration curve regardless of turnout standard (100 or 130 km/h).
- The speed restriction at the exit loop prolongs the cycle time through extended run times. However the extension limits to the braking, since the following acceleration course is performed outside the single-track section, where the train route is already released.

Figure 10 shows the resulting additional delays. These delays are calculated as a sum:

Each train suffer delay due to braking before the entrance track loop, waiting for clearance and then finally due to speed restrictions imposed by preceding trains and/or turnouts when passing the temporary single-track section.

During maximum capacity operation all trains are likely to stop and wait at the entrance track loop. The waiting time is here assumed to be half the cycle time. This makes the waiting time the most time consuming part, responsible for 60-90 % of the total delay.

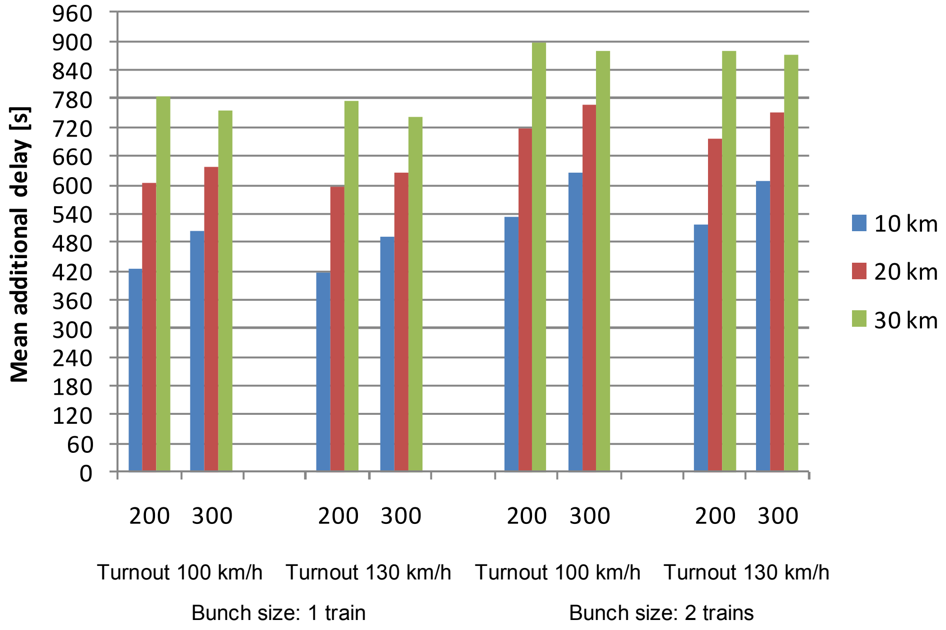


Figure 10 Mean additional delay caused by temporary single-track operation. Each bar shows the number of trains per hour that can be operated in each direction given maximum speed (200 or 300 km/h), turnout standard (100 or 130 km/h), bunch size (1 or 2 trains at a time) and a specified inter-loop distance (10, 20 or 30 km).

This fact is seen in figure 10 where the inter-loop distance, that strongly influences the cycle time, has a major impact on the additional delay caused to the trains. Bunched operation prolongs the delays due to longer cycle times. This is the price to be paid for increased capacity.

Another important result is that the faster trains suffer more delays than the slower ones when the inter-loop distance is 10 or 20 km. A longer distance, however, favours the faster trains since they can traverse the single-track section faster which gives a shorter cycle time. The turnout speed is a bit more important for the additional delay than the capacity.

It is of interest to focus on the three most important factors: the inter-loop distance, the bunch size and the maximum speed (vehicle type). Figure 11 and 12 shows how the inter-loop distance affect the maximum capacity and the additional delay respectively for the four combinations of bunch size and maximum speed. The turnout speed is here fixed to 100 km/h and the inter-loop distance is increased stepwise by 1 km from 10 to 30 km.

Figure 11 is very useful since it can be used to choose a feasible inter-loop distance, given a required capacity level. The figure shows the features discussed above: faster trains give higher capacity for a given inter-loop distance and the difference between fast and slow trains increases with the inter-loop distance. Bunched operation is more beneficial, compared to one-by-one operation, for long inter-loop distances.

The corresponding figure for the additional delay is somewhat more complicated. Slower trains are more sensitive to the inter-loop distance since they lose less in each braking and acceleration course. On the other hand, a lower maximum speed increases the cycle time through longer traversing times. This is seen for the longest inter-loop distances where the faster trains suffer less additional delay than the slower ones.

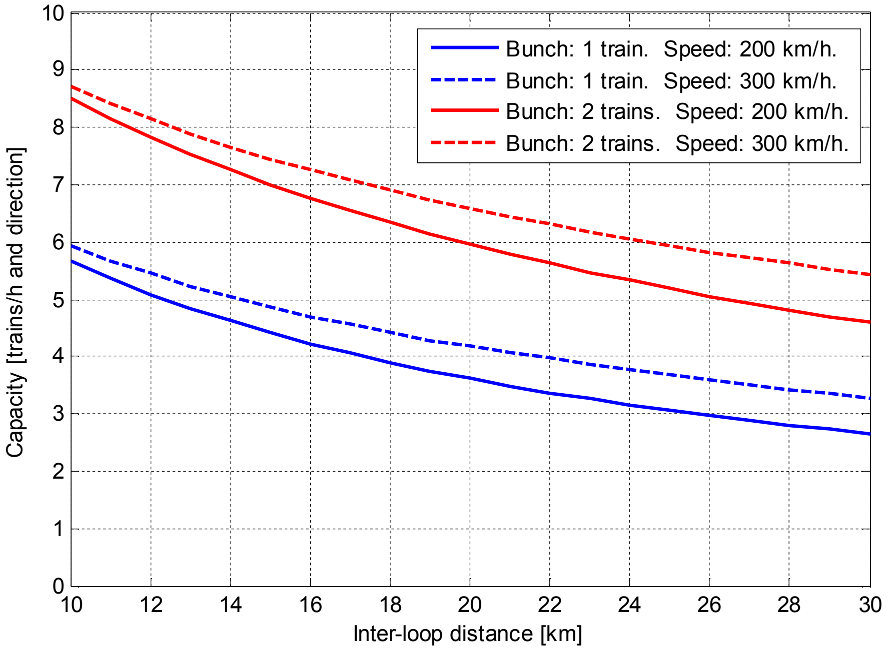


Figure 11 Maximum capacity for temporary single-track operation. Turnout speed fixed to 100 km/h.

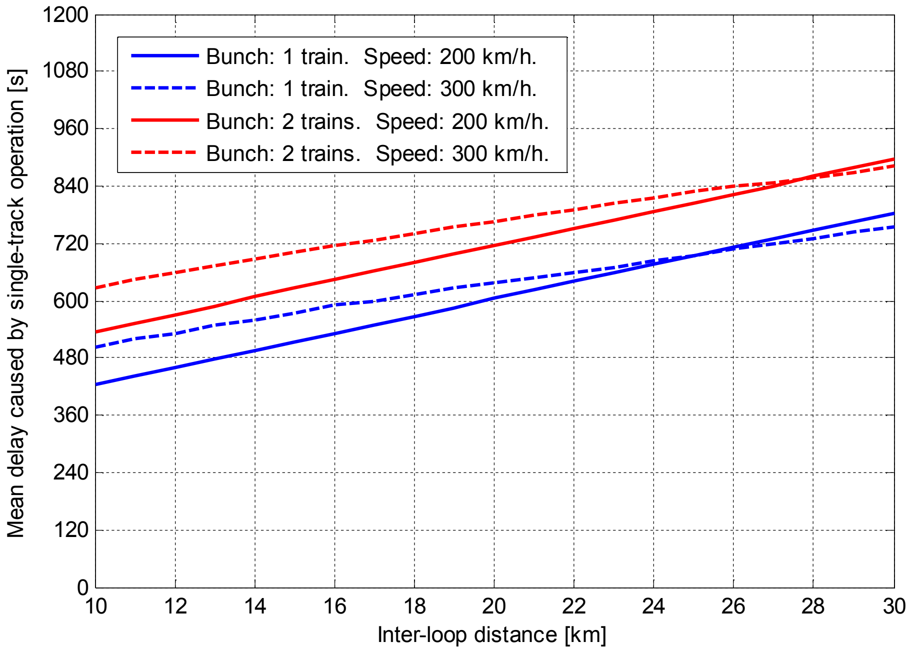


Figure 12 Mean additional delay caused by temporary single-track operation. Turnout speed fixed to 100 km/h.

Minimum additional delay operation

The previous section showed capacity and additional delay for temporary single-track operation where the arriving process of the trains is unknown. This lack of knowledge forced us to assume all trains to stop at the entrance track loop and wait for clearance. This waiting implied additional delay to the trains and just the waiting time was the major part of the total added delay.

It is possible to eliminate this waiting time and let the trains pass the temporary single-track section with a minimum of delay. This requires the trains to arrive in an optimal sequence and with optimal time distances. In this case the track loop is cleared already when an approaching train is at braking distance from the loop, so that it does not have to brake for a stop signal.

Figure 13 shows the capacity for this type of optimised operation. Only one-by-one operation is considered, i.e. the traffic direction on the single-track section is changed after each single train. The figure shows that the capacity is almost the same as is the case when the trains have to stop and wait at the entrance track loop. This is a good condition since it tells that capacity (throughput) is almost independent of the timetable design. This is probably due to good acceleration and deceleration characteristics of the chosen vehicles.

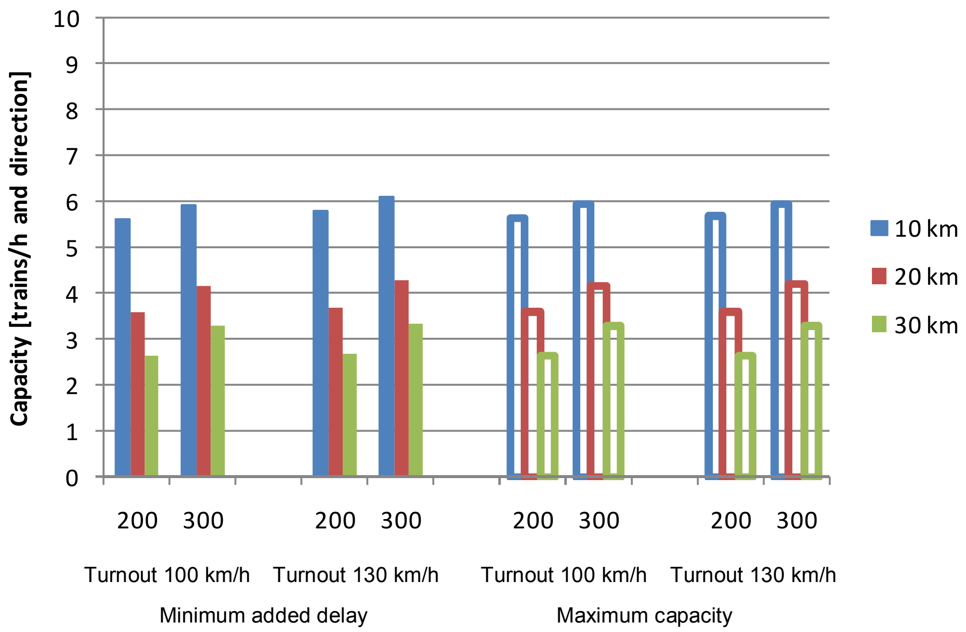


Figure 13 Capacity for temporary single-track operation. Two train speeds: 200 and 300 km/h.

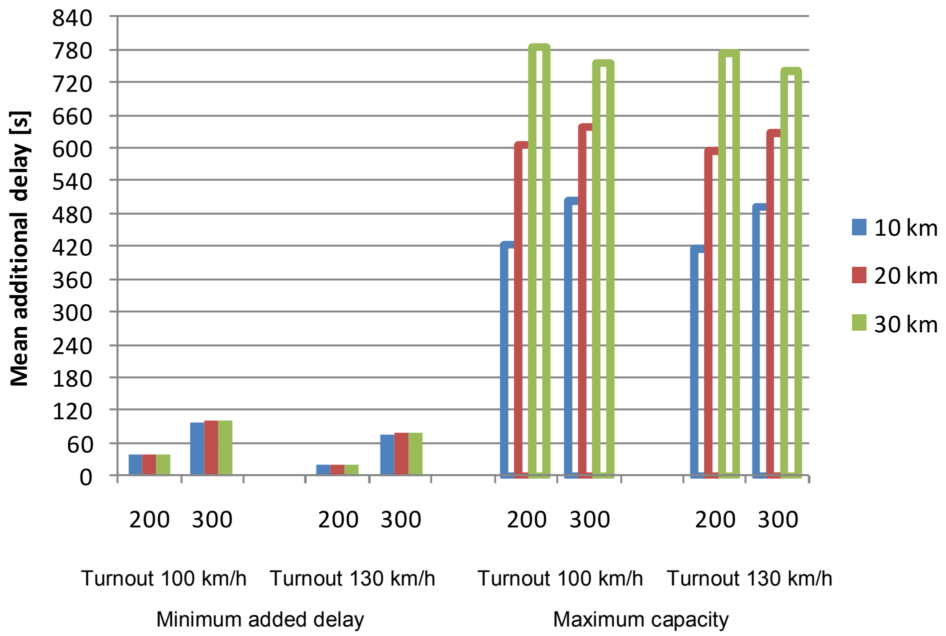


Figure 14 Mean additional delay caused by temporary single-track operation. Two train speeds: 200 and 300 km/h.

The additional delays, see figure 14, are different. These delays can be kept to a minimum since no train has to wait for clearance. Trains that use their "normal" track through the single-track section do not suffer any additional delay at all. Switching trains have to brake twice for the turnouts at the entrance and exit track loops. This fact is seen in a clear difference in additional delay between different turnout standards. A shift from 100 to 130 km/h in the turnout would reduce the additional delay by 20-40% or 15-20 seconds per train.
Figure 14 also shows that the additional delay is independent of the inter-loop distance. This is reasonable since the distance is already taken into account when the trains are separated in time in order to avoid waiting.

The results for minimum additional delay operation are useful when the timetable is completely adjusted to a single pair of track loops. Such an adjustment is an absolute condition to achieve minimum delay. This is practically impossible since the timetable changes and develops over time. Furthermore, it is also impossible to get an optimal timetable for every pair of track loops.

For these reasons we have to accept additional delays that are significantly higher than the low values shown in figure 14.

Conclusions

The two design parameters studied in this report, the inter-loop distance and the turnout standard, have to be chosen with respect to traffic intensity, maximum speed for the trains and operational requirements.

The analysis of passing loops and double track capacity, see a previous chapter, showed that the capacity for mixed traffic is 4-6 trains/h and direction. A reasonable requirement for the track loops is then that they shall manage this design capacity, so that cancelation of trains can be avoided.

Requirements for low additional delays are assumed to be secondary. This is reasonable as long as the track loops are used only for redundancy and not used in the normal, scheduled operation. This leads to the conclusion that the turnout standard is not a key factor. It is therefore reasonable to use the moderate turnout standard of 100 km/h for track loops that are used mainly for redundancy.

One exception from this recommendation is one-sided passing loops where the track loop turnouts can be given a higher standard to ensure time and capacity efficient overtakings.

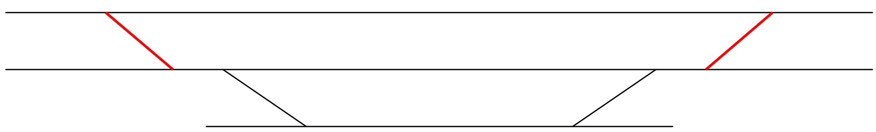


Figure 15 One sided passing loop. The track loop turnouts (red) could here be given the same standard (130 km/h) as the passing loop turnouts if the loop is planned to be used for overtakings in both directions.

The choice of a turnout standard of 100 km/h is not very controversial since the speed restriction does not affect the capacity nor the additional delay caused to the trains during the kind of stop-and-wait operation that is normal in temporary single-track operation.

The inter-loop distance is a more important design factor. A capacity requirement of 4-6 trains/h and direction means that an inter-loop distance of 18-20 km is needed, according to figure 11. This distance makes it possible to operate 4 trains/h and direction in one-by-one operation and at least 6 trains/h and direction in bunched operation. A distance of 18-20 km/h requires a maximum speed of at least 200 km/h. On line sections with lower maximum speed, or in case some of the trains have a lower maximum speed, the distance should be reduced in order to reach the required capacity.

The expected additional delay will be 10-12 minutes/train. This delay level applies for improvised single-track operation and can be significantly reduced if the timetable is adjusted for single-track operation imposed by planned maintenance works etc.

Further studies

This study has shown that the capacity for temporary single-track operation can be calculated with high accuracy. The other measure of performance, the additional delay, has been treated in a more simplified way since it is timetable dependent. It is therefore natural to perform deeper studies of the influence of timetable, or rather the arriving process of the trains, to find out if the waiting time can be further reduced in some way. Such analyses can be performed with combinatorial methods.

References

Berg von Linde O., (2002). Projekt Tegelbacken – en kapacitetsbetraktelse, Tåg Otto HB Rapport 2002-19. (in Swedish)

Appendix 1

Train data

Table A1. Basic train data for ICE3 Velaro and Generic EMU on level track.

	ICE3 Velaro E	Regional Generic EMU
Speed in study	Utilized top speed in study: 300 km/h (maximum top speed 350 km/h)	200 km/h
Max power	8800 kW	9600 kW
Starting effort	280 kN	353 kN
Starting acceleration Level track	0.60 m/s^2	0.70 m/s^2
Average deceleration	0.8 m/s^2	0.8 m/s^2
Acceleration time to top speed	300 s (0-300 km/h)	125s (0-200 km/h)
Acceleration distance to top speed	17000 m (0-300 km/h)	4100 m (0-200 km/h)
Mass	440 t	420 t
Length	200 m	200 m

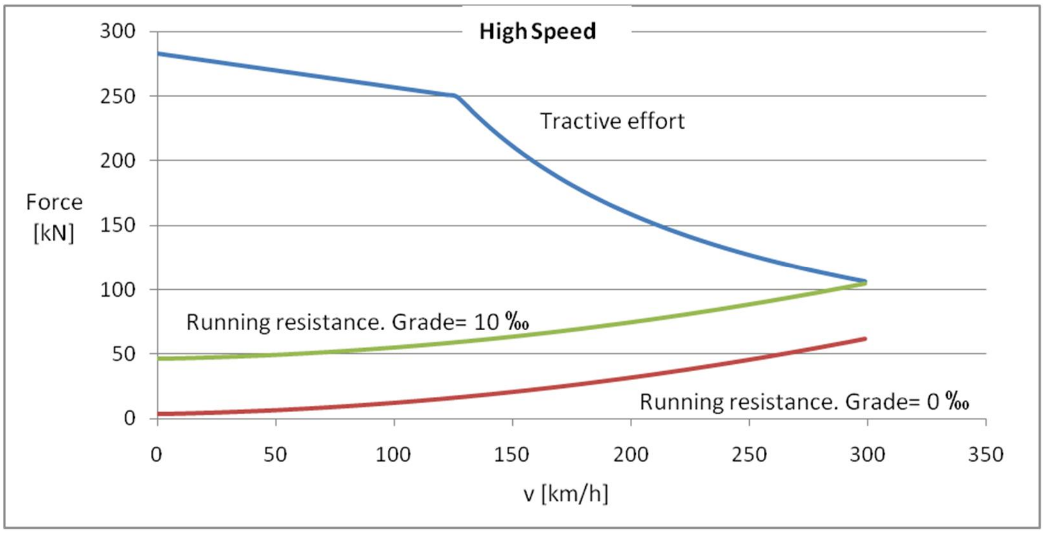


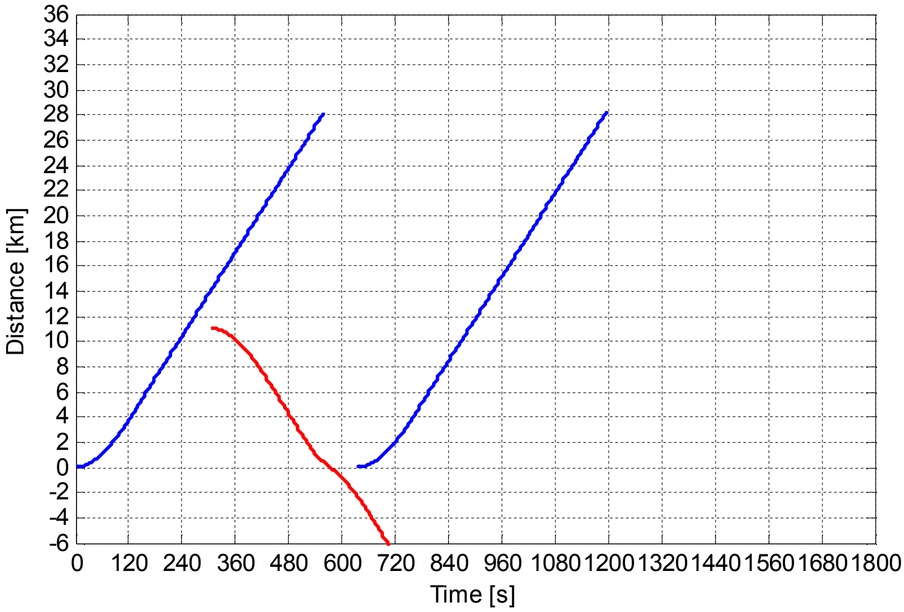
Figure 16. Tractive effort and runnnig resistance for ICE3 Velaro- E in grades of 0 and 10 permille up to 300 km/h (ICE3 Velaro can run up to a speed of 350 km/h).

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

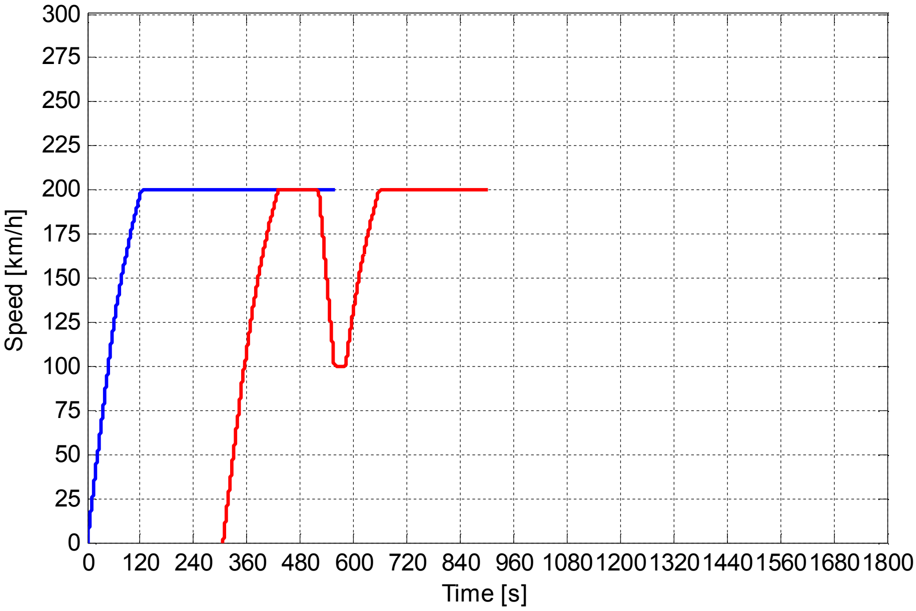
Appendix 2

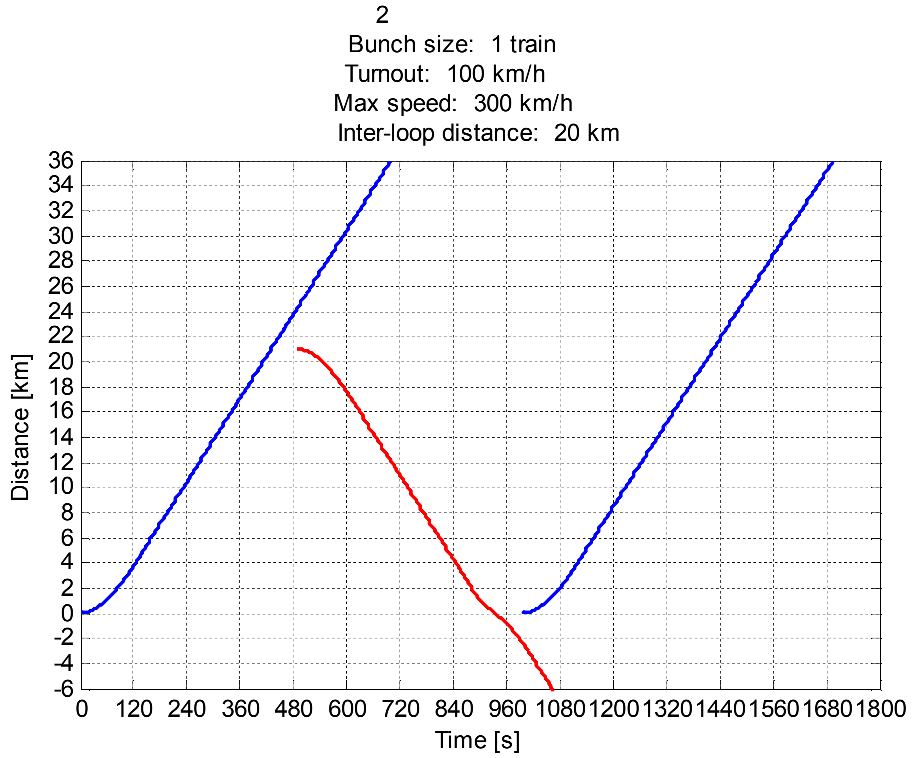
Graphical timetables and speed diagrams for maximum capacity operation. Blue trains use their ordinary track, without switching. Red trains switch both at entrance and exit track loop.

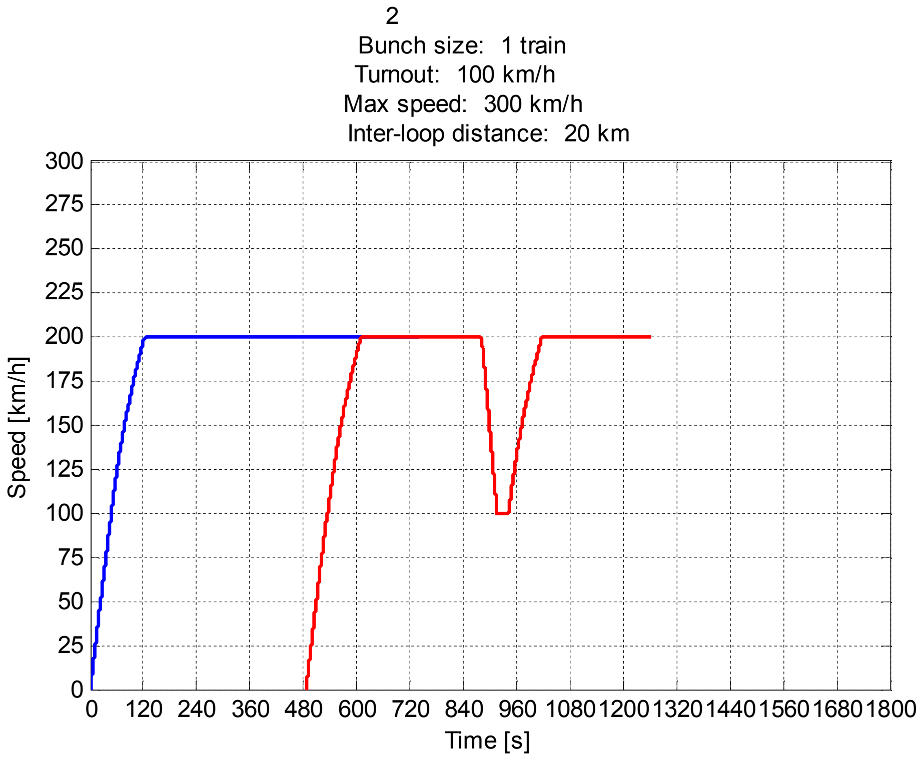
1
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km

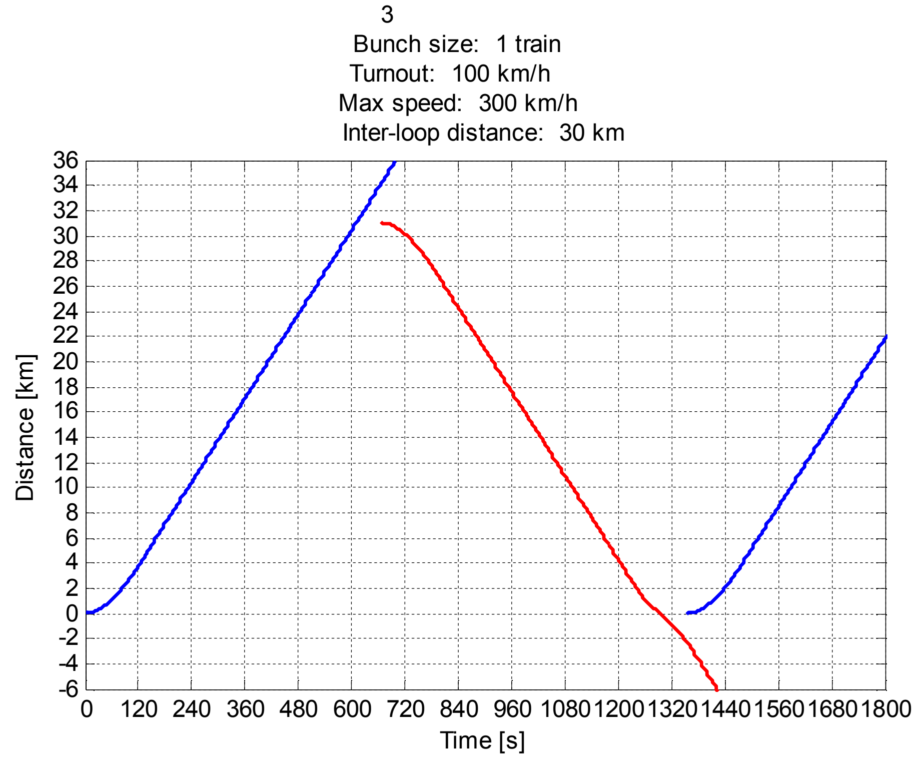


1
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km




2
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


2
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


3
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Distance [km]
36
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32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
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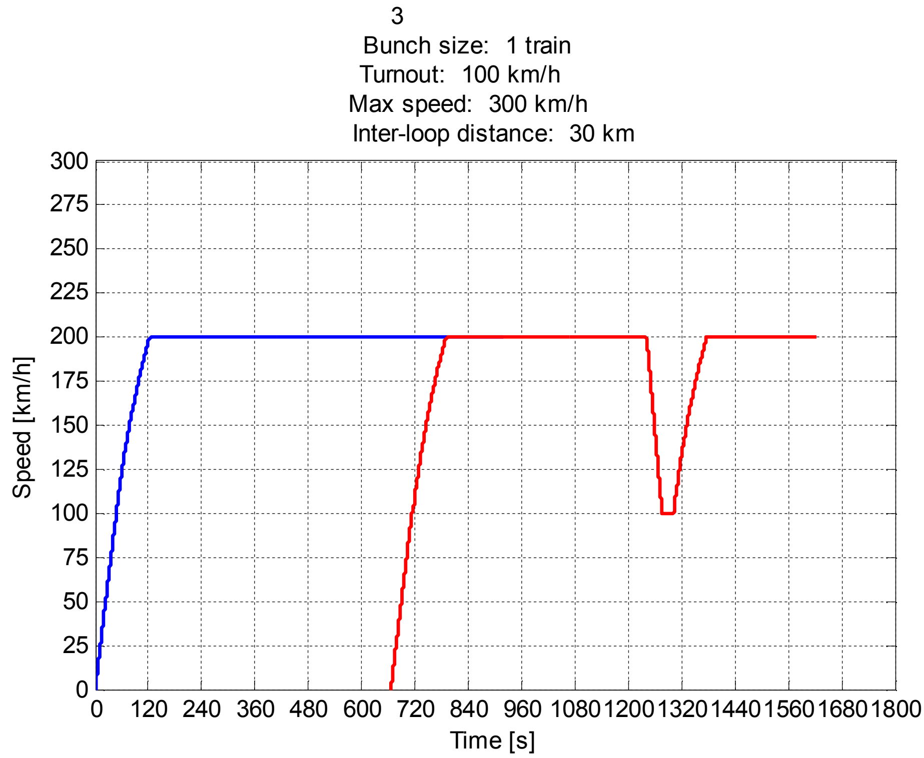
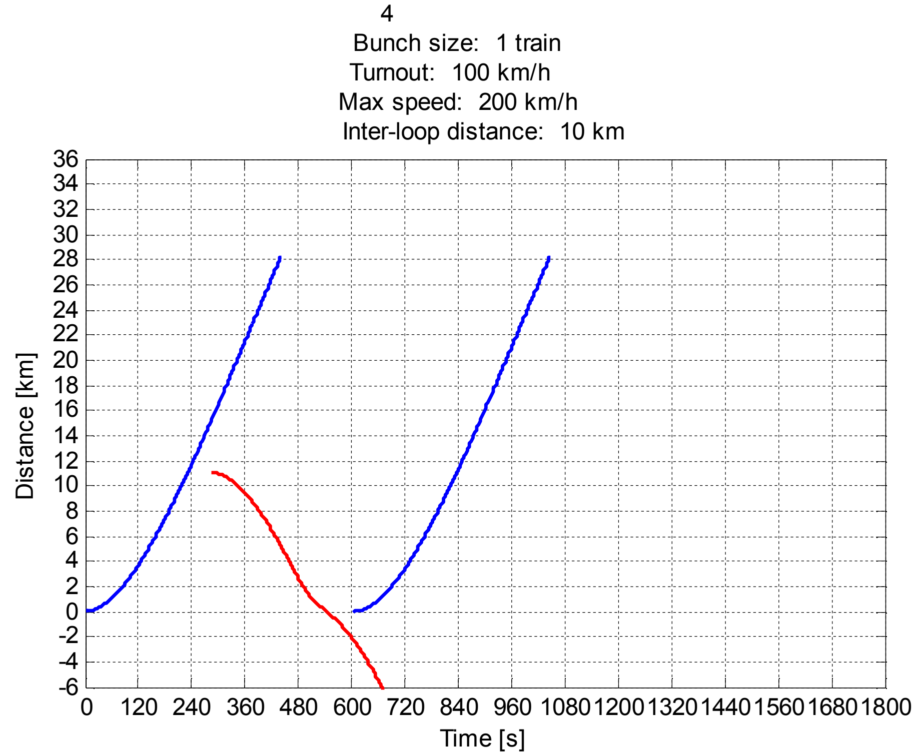
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


3
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


4
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
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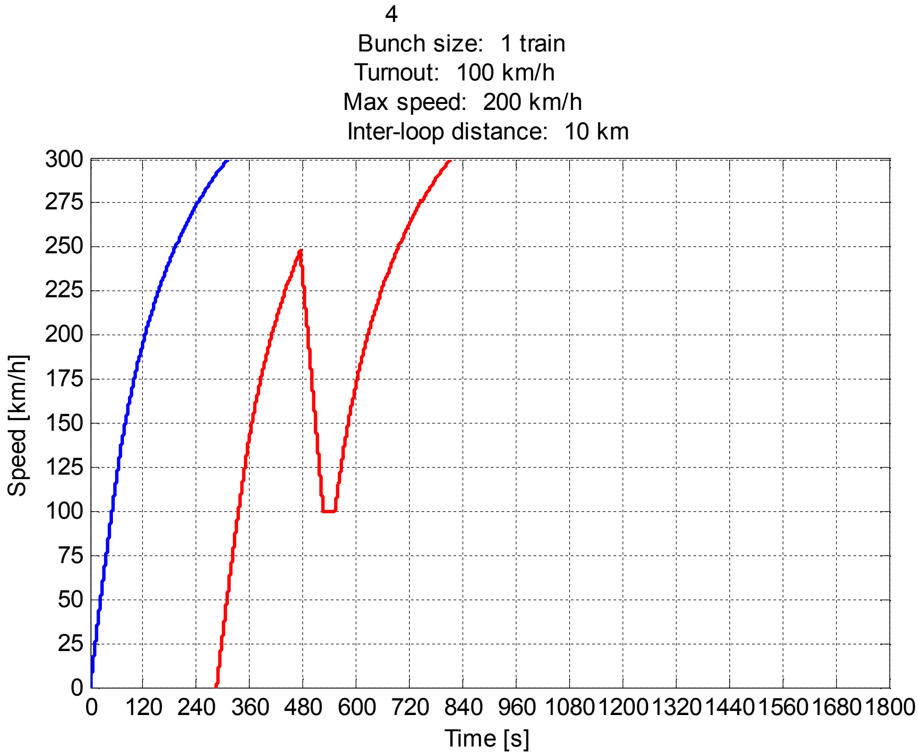
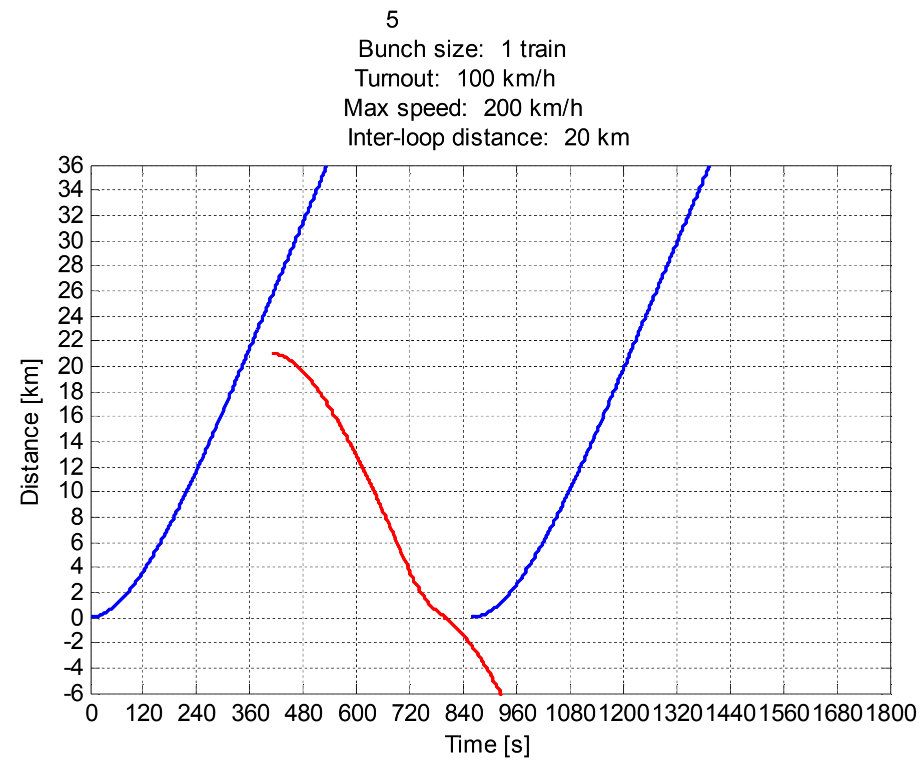
4
2
0
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


4
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


5
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
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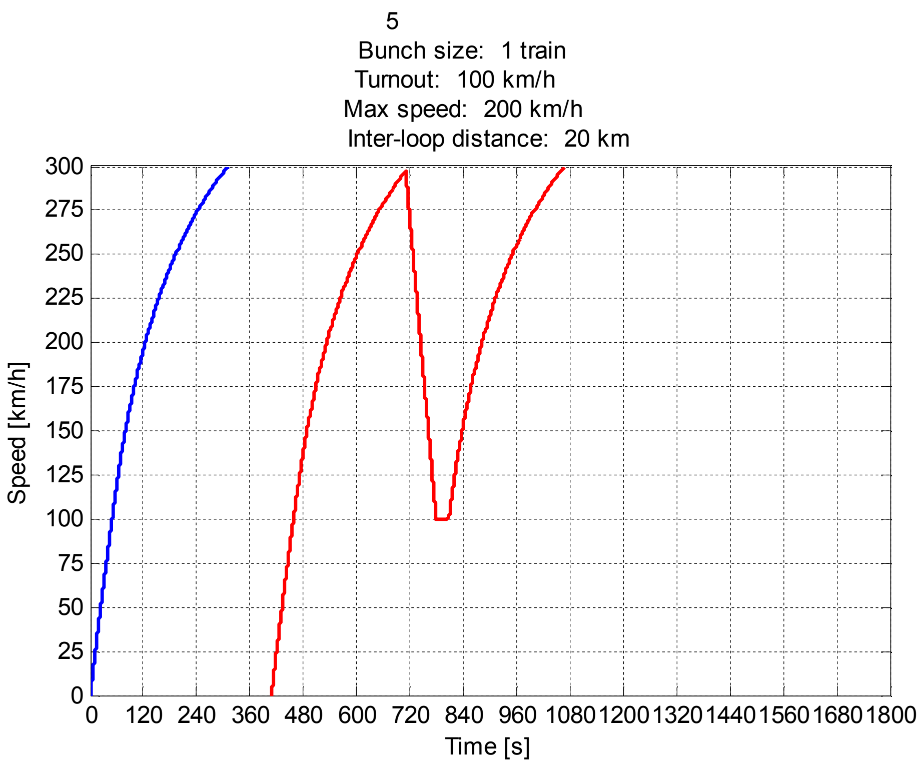
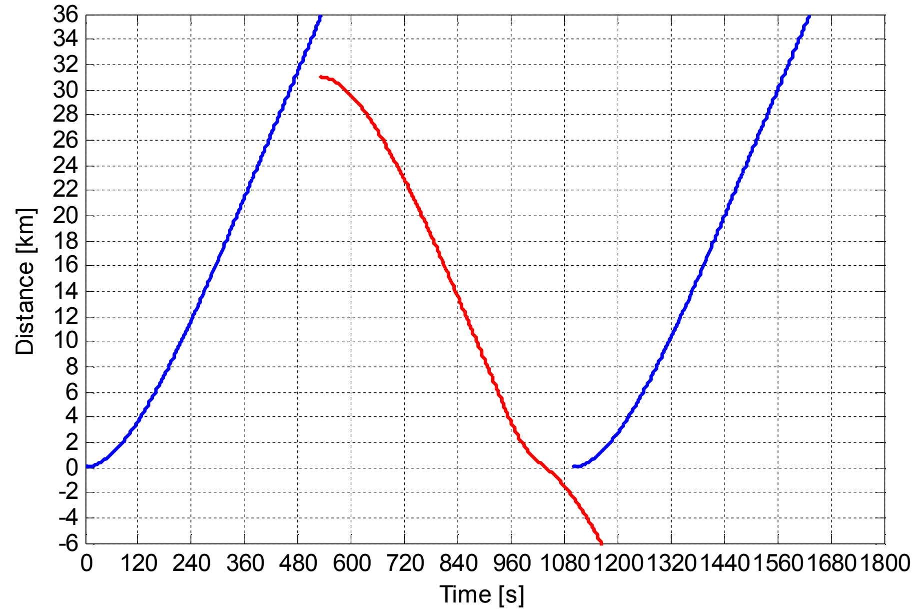
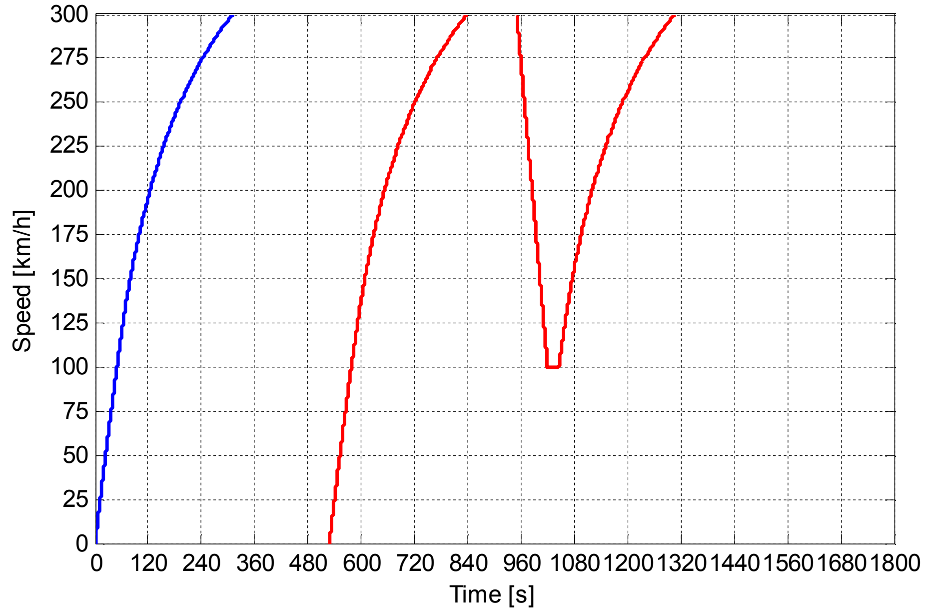
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]

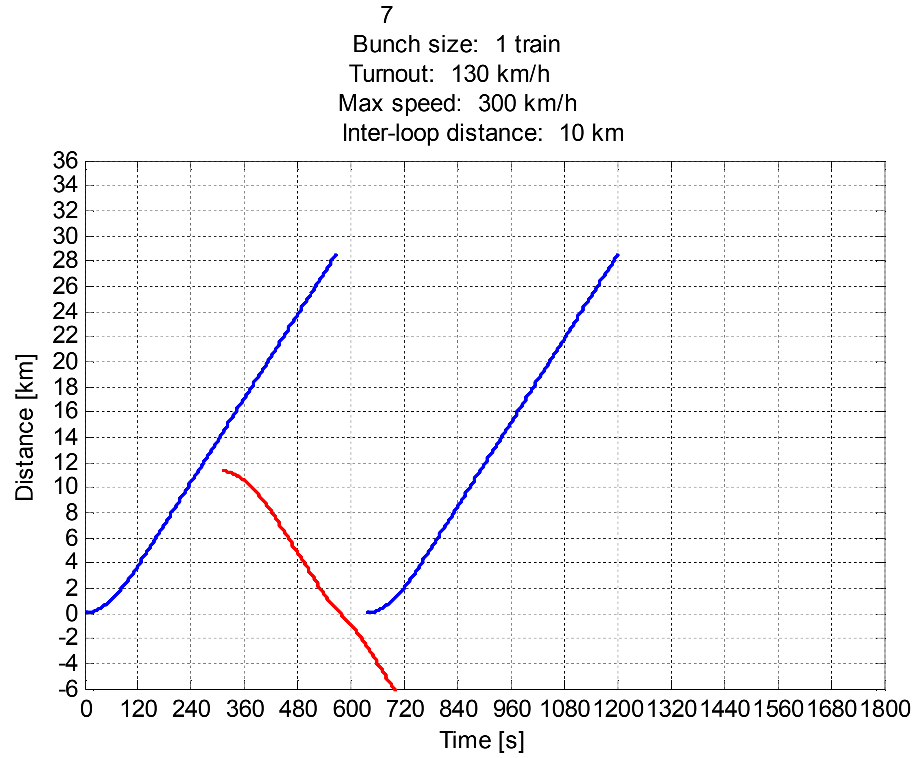

5
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]

6
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km



6
Bunch size: 1 train
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km




7
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Distance [km]
36
34
32
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28
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24
22
20
18
16
14
12
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8
6
4
2
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-2
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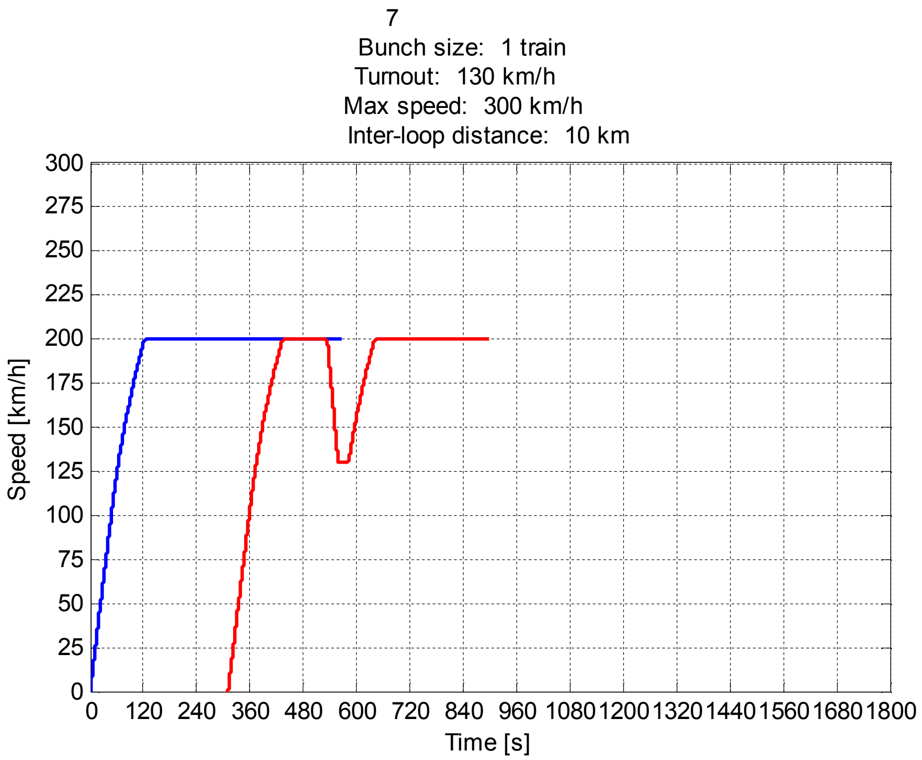
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


7
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Speed [km/h]
300
275
250
225
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175
150
125
100
75
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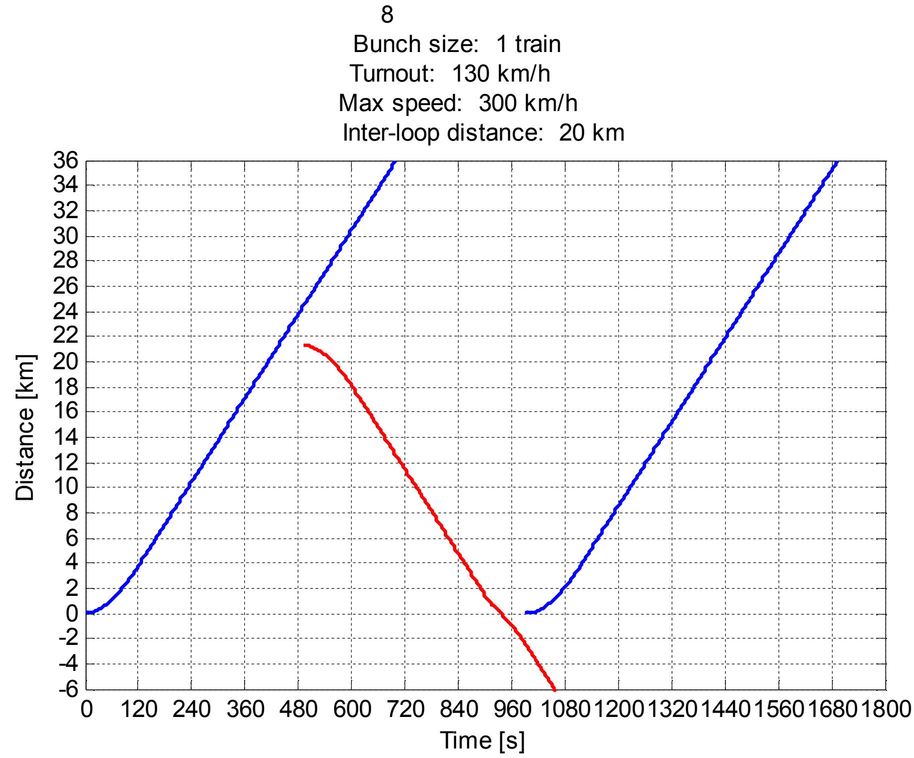
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


8
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Distance [km]
Time [s]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
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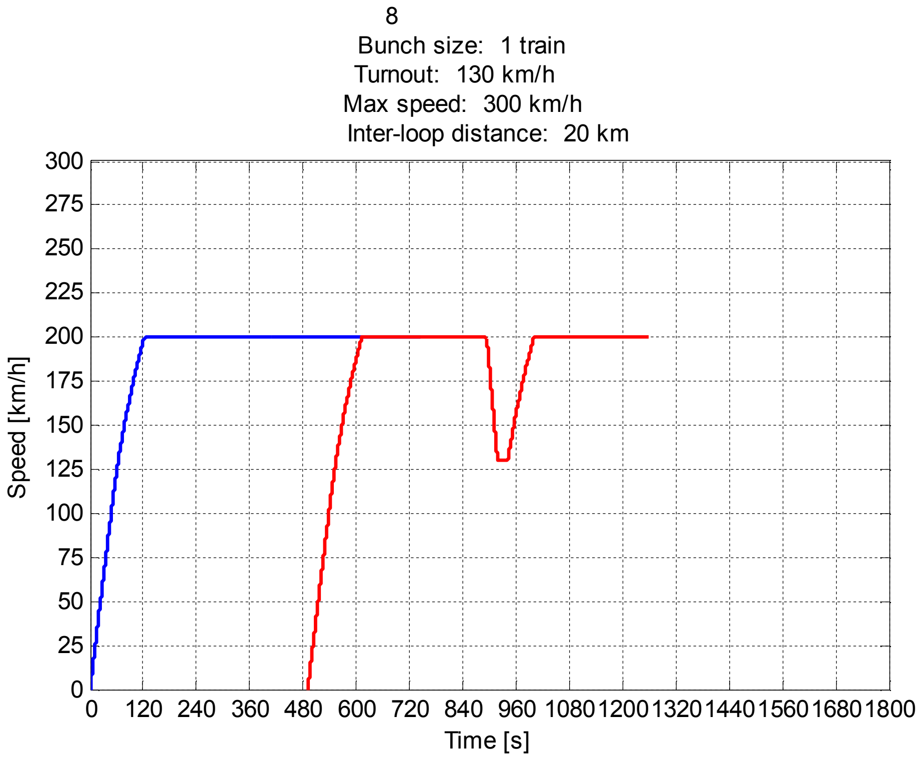
1080
1200
1320
1440
1560
1680
1800


8
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Speed [km/h]
Time [s]
300
275
250
225
200
175
150
125
100
75
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960
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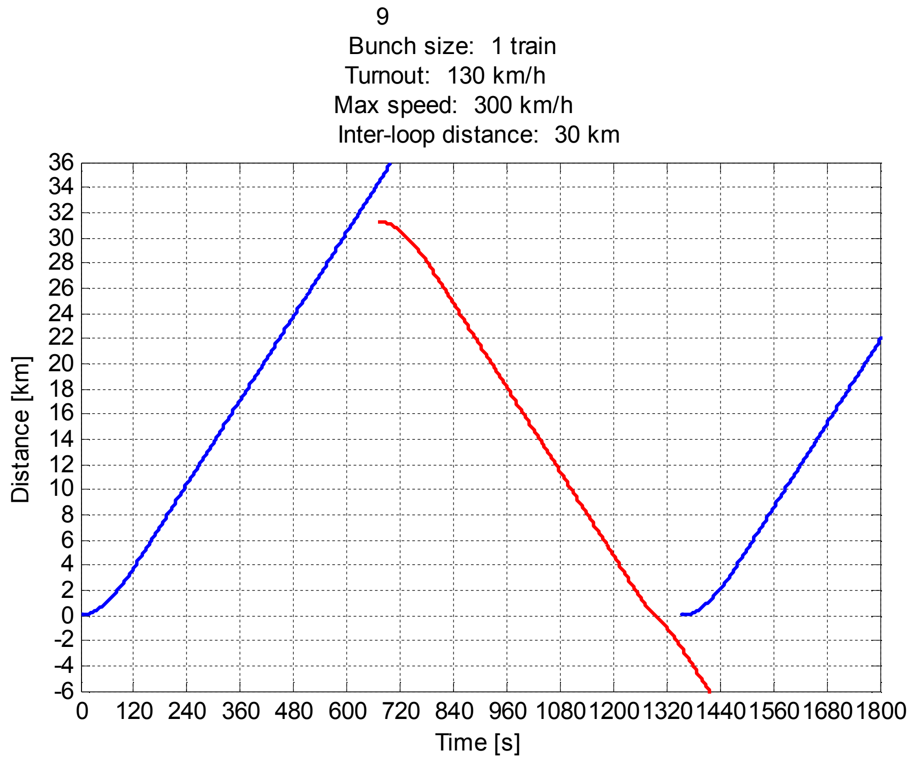
1680
1800


9
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Distance [km]
36
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32
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28
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24
22
20
18
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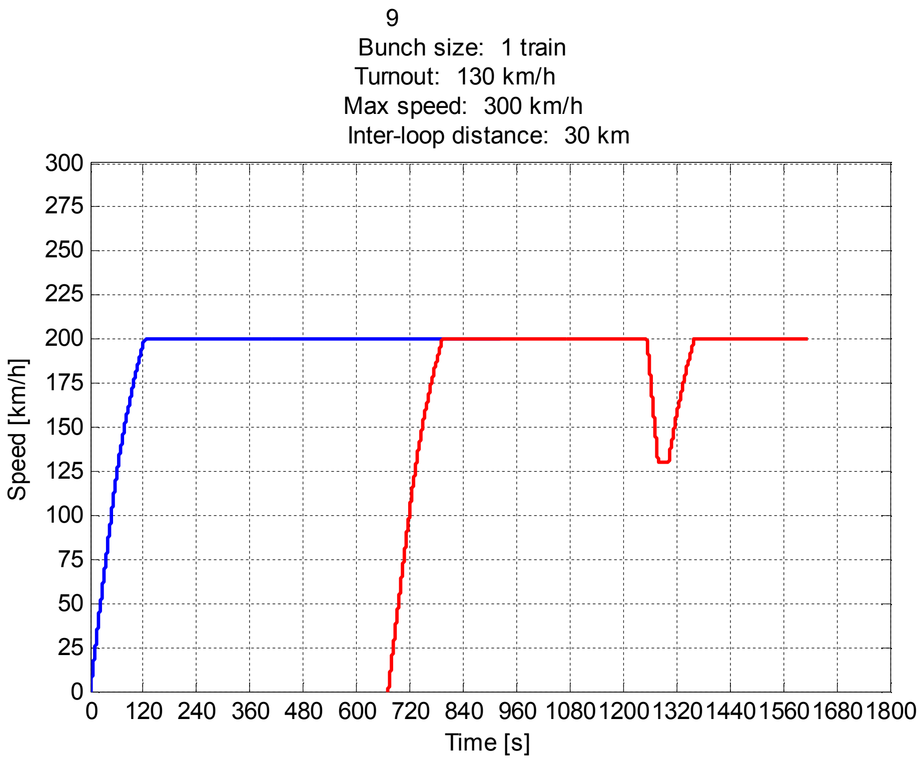
1200
1320
1440
1560
1680
1800
Time [s]


9
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
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120
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360
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720
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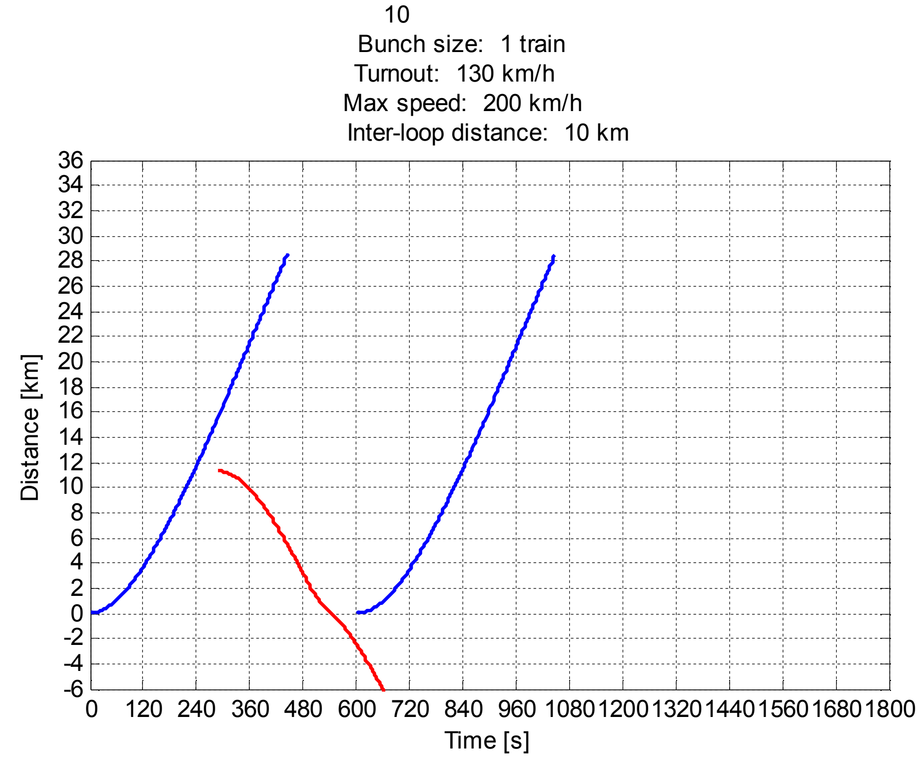
960
1080
1200
1320
1440
1560
1680
1800
Time [s]


10
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Distance [km]
Time [s]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
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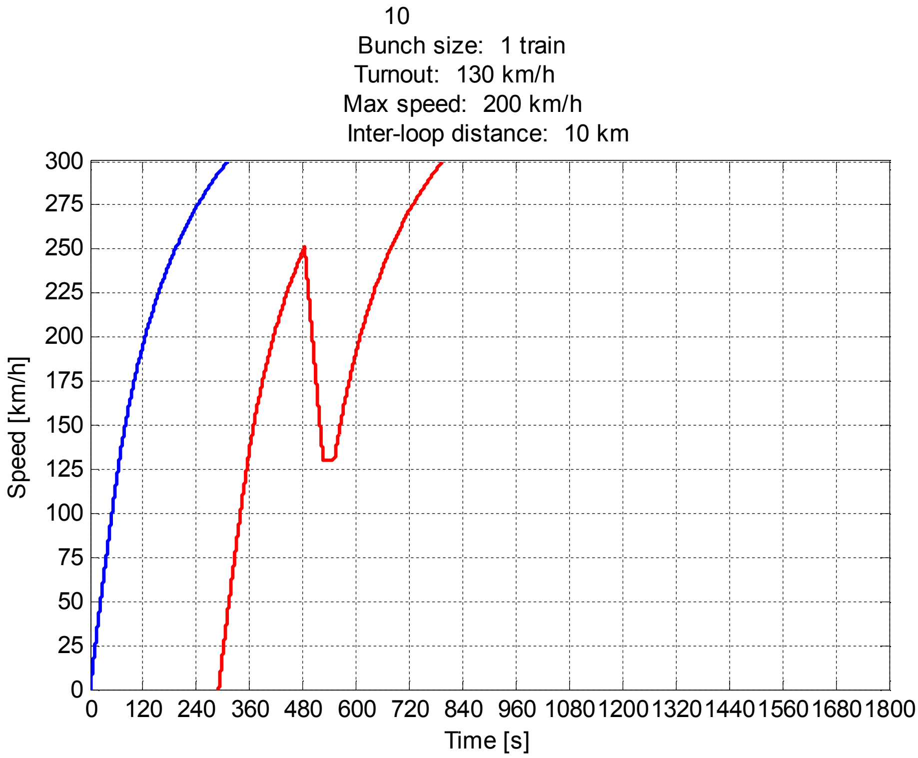
1320
1440
1560
1680
1800


10
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Speed [km/h]
Time [s]
300
275
250
225
200
175
150
125
100
75
50
25
0
0
120
240
360
480
600
720
840
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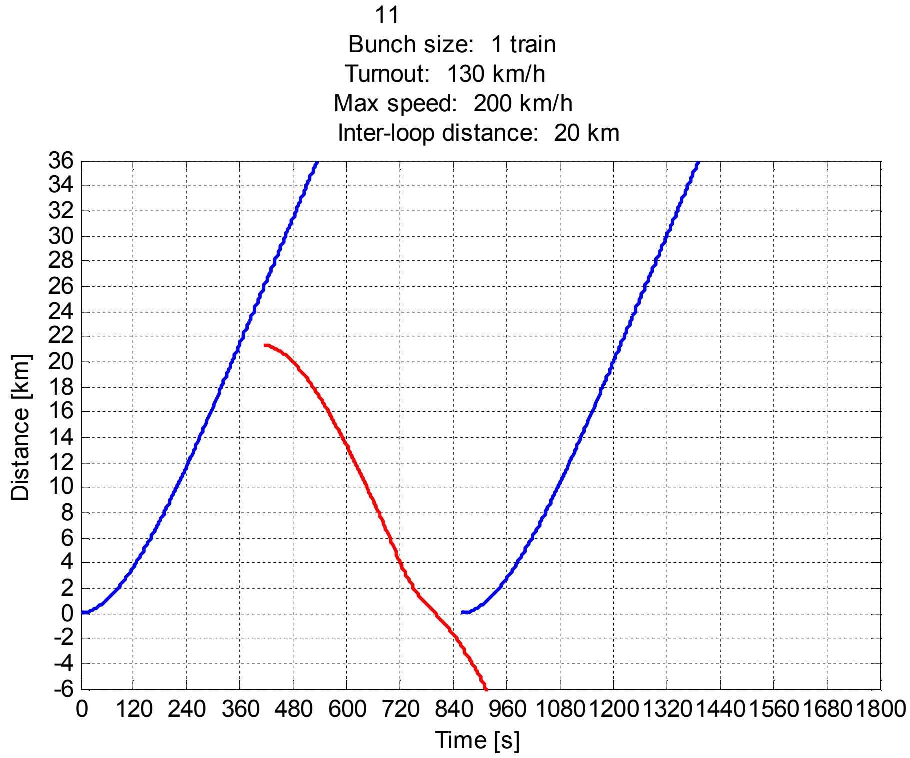
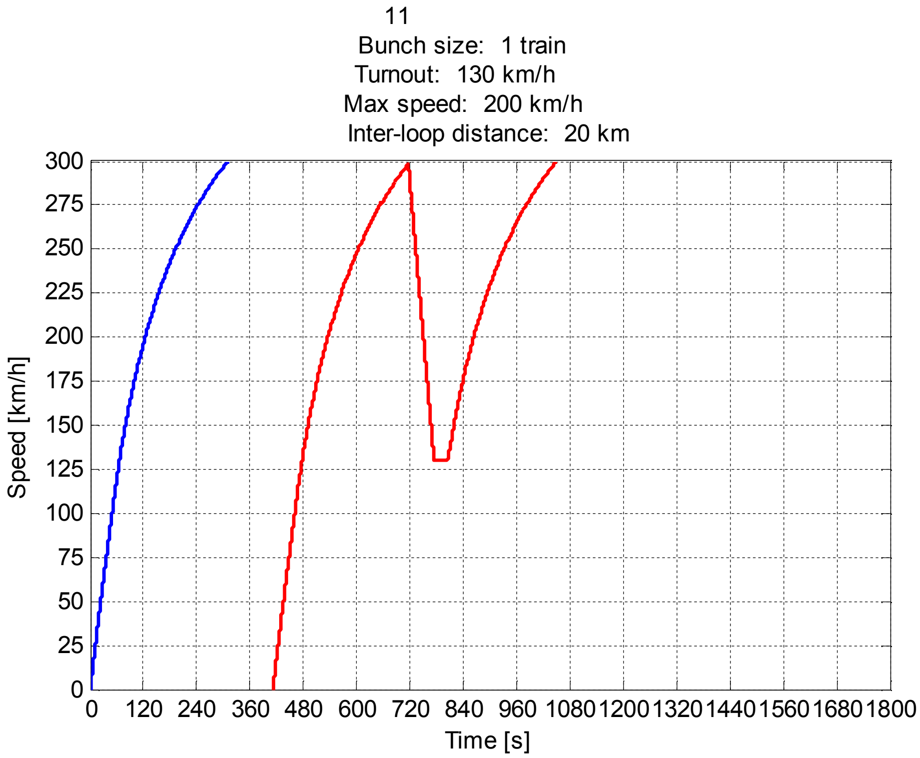
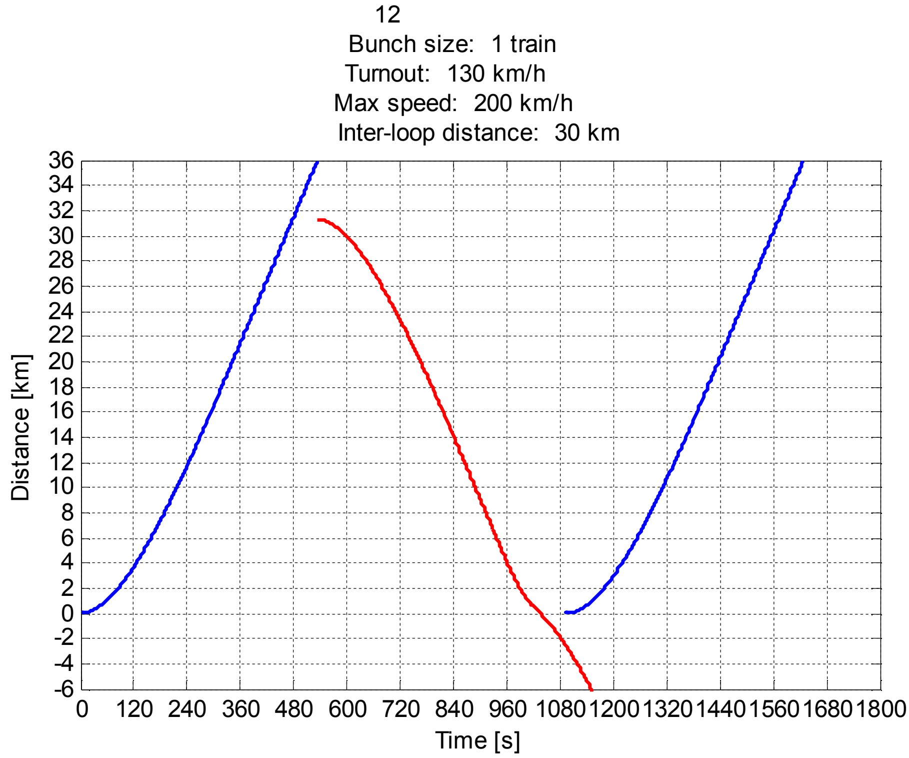
1200
1320
1440
1560
1680
1800


11
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


11
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


12
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Distance [km]
Time [s]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
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4
2
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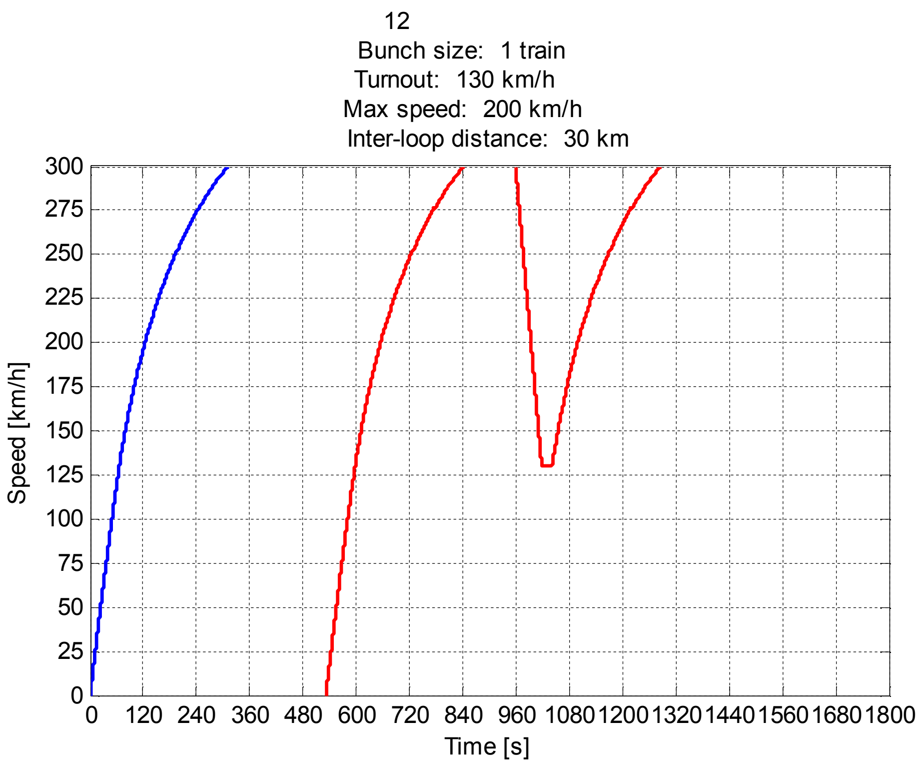
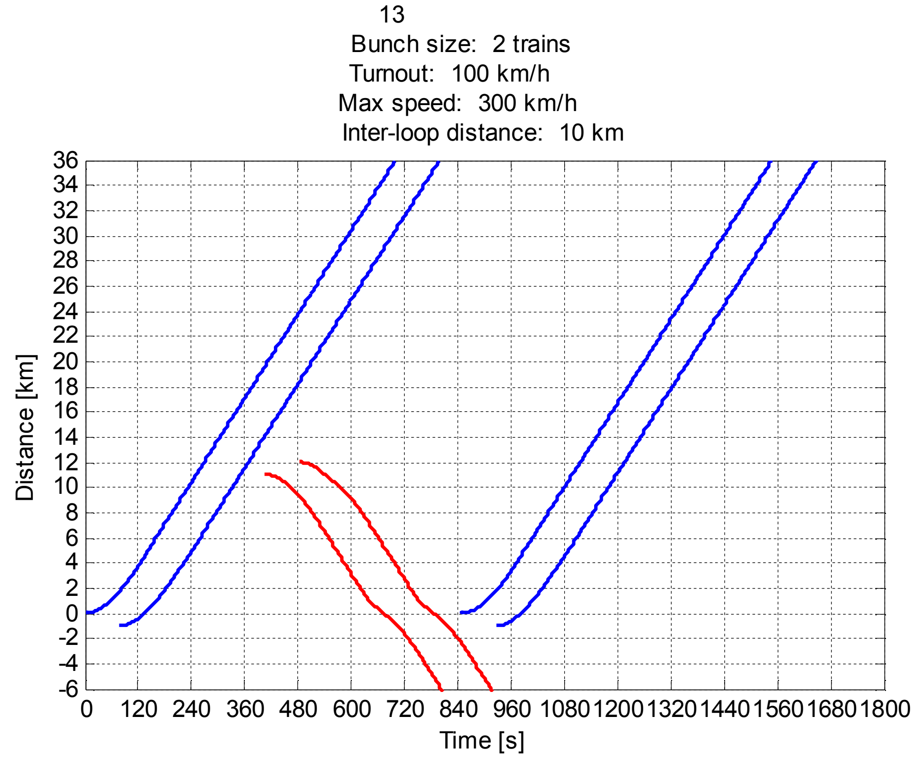
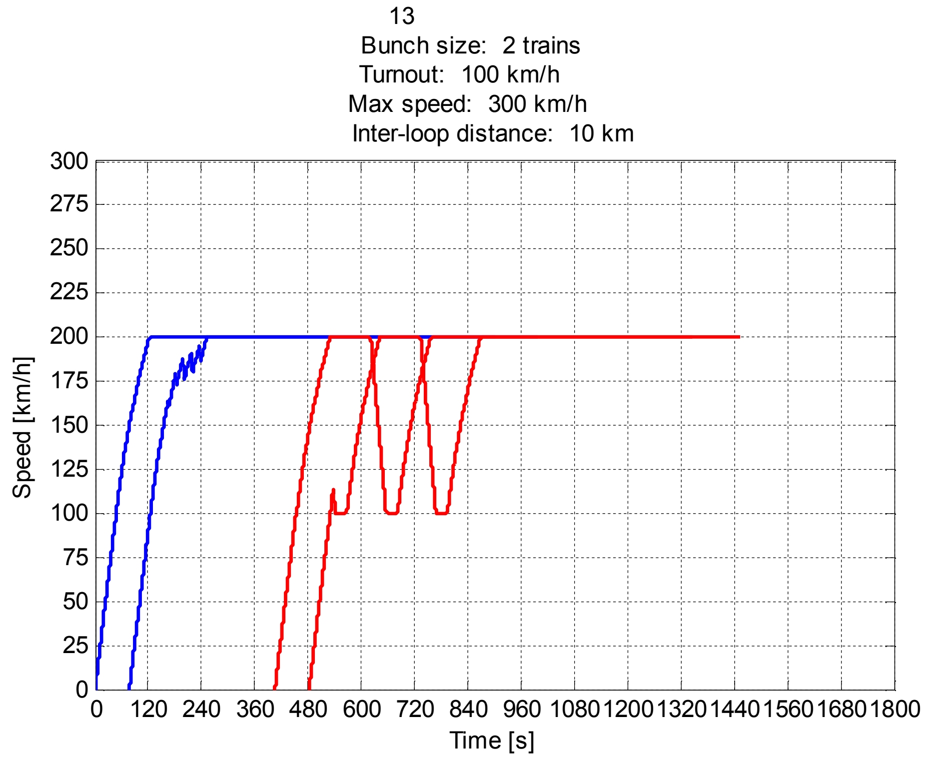
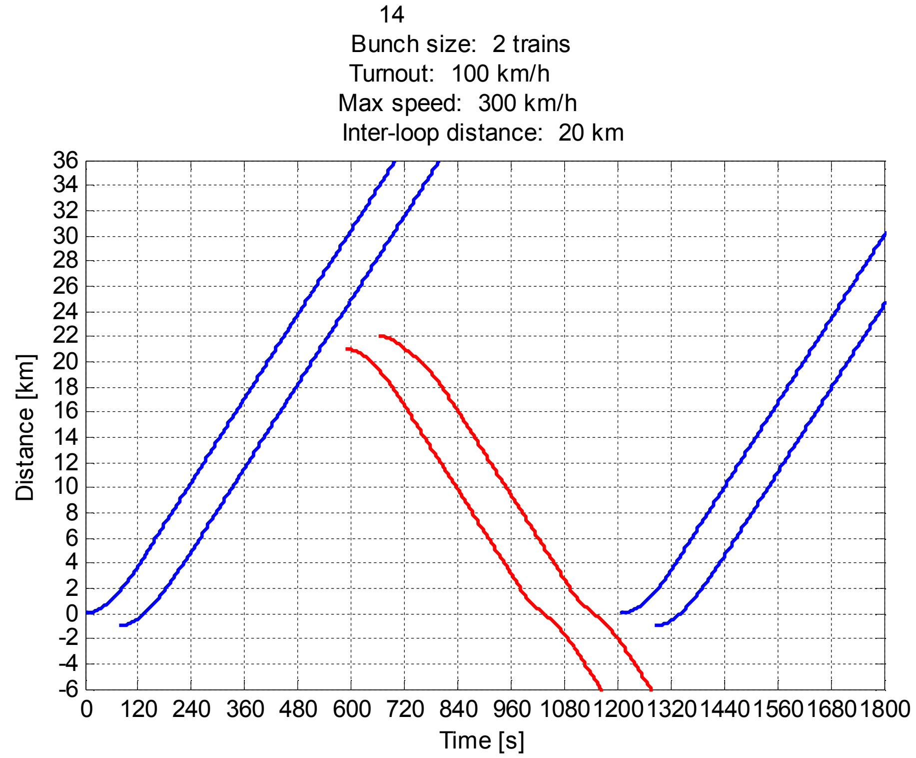
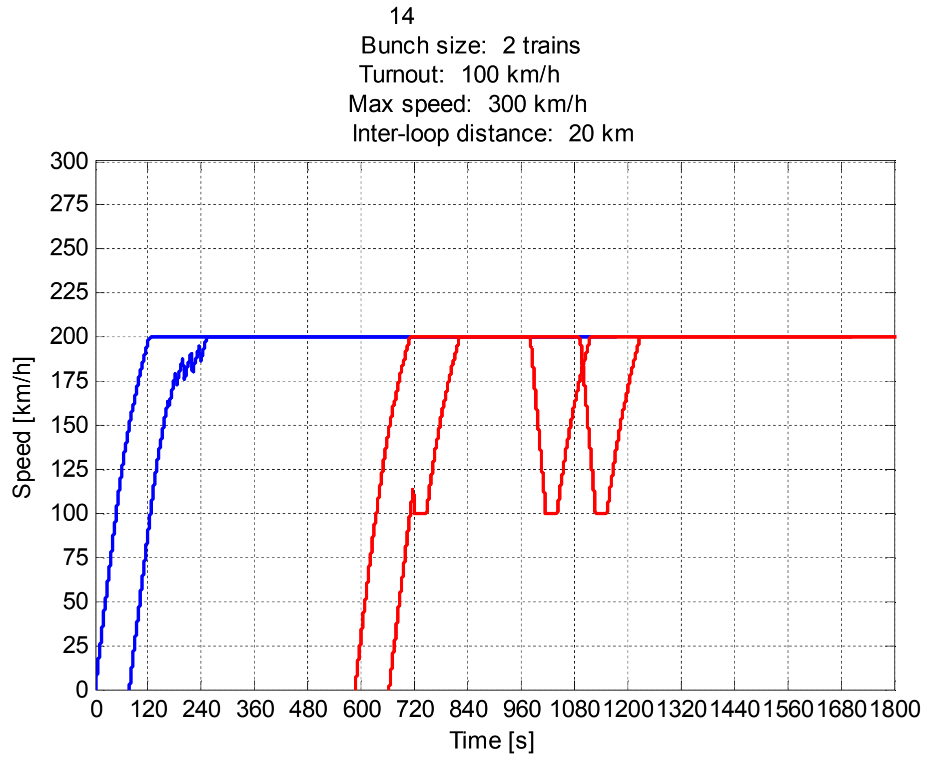
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800

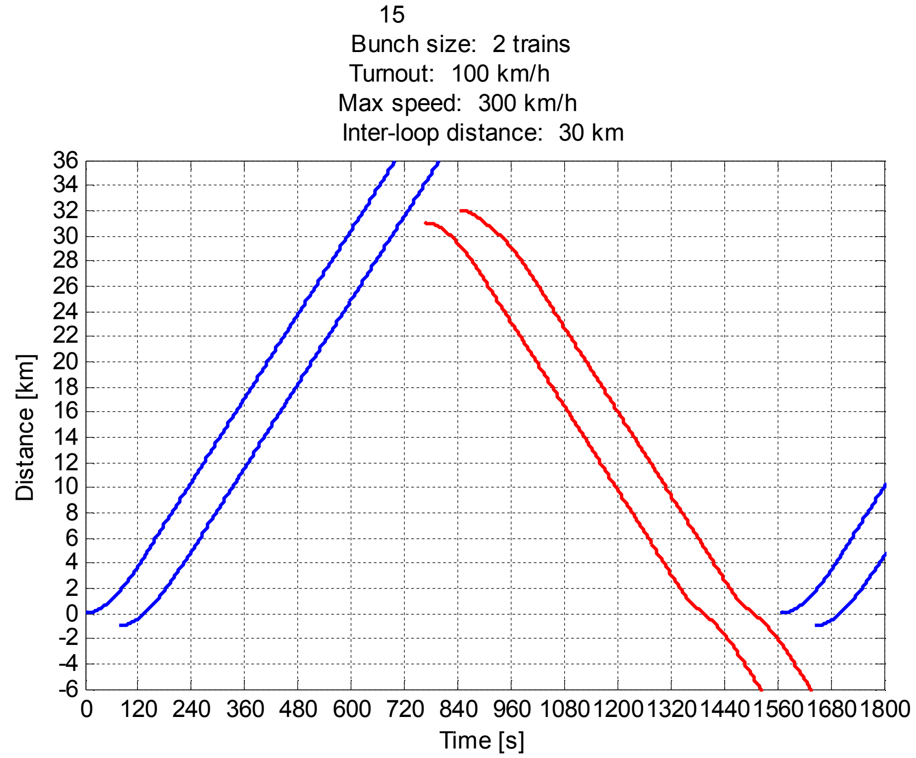

12
Bunch size: 1 train
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Speed [km/h]
Time [s]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800


13
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Distance [km]
Time [s]


13
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Speed [km/h]
Time [s]


14
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Distance [km]
36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0 -2 -4 -6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


14
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Speed [km/h]
300 275 250 225 200 175 150 125 100 75 50 25 0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


15
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
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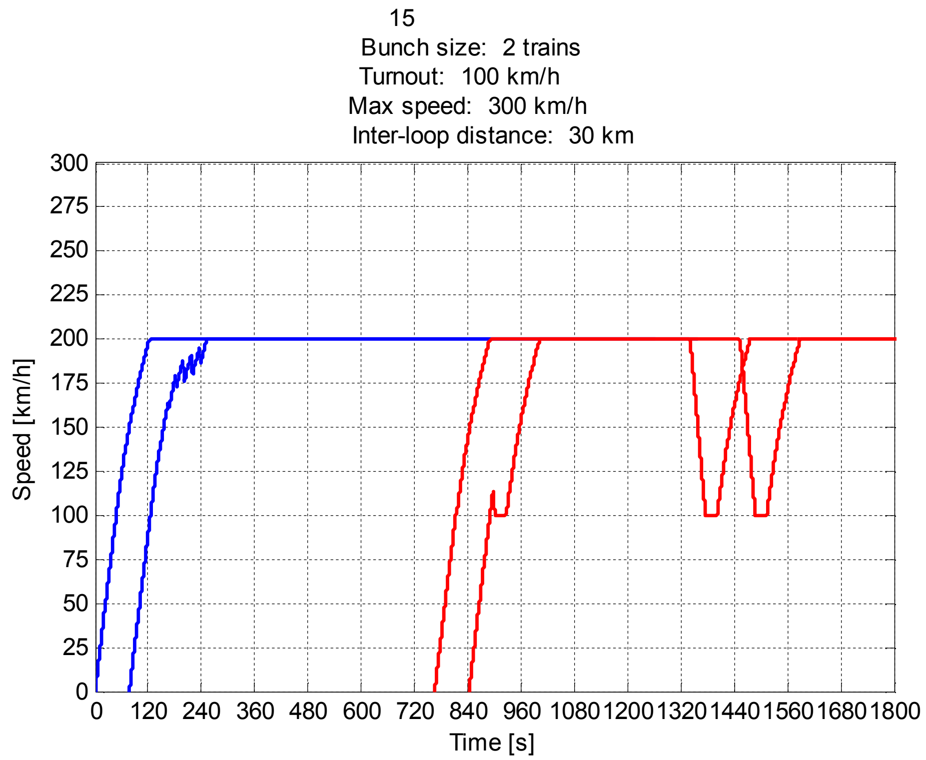
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
Time [s]


15
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
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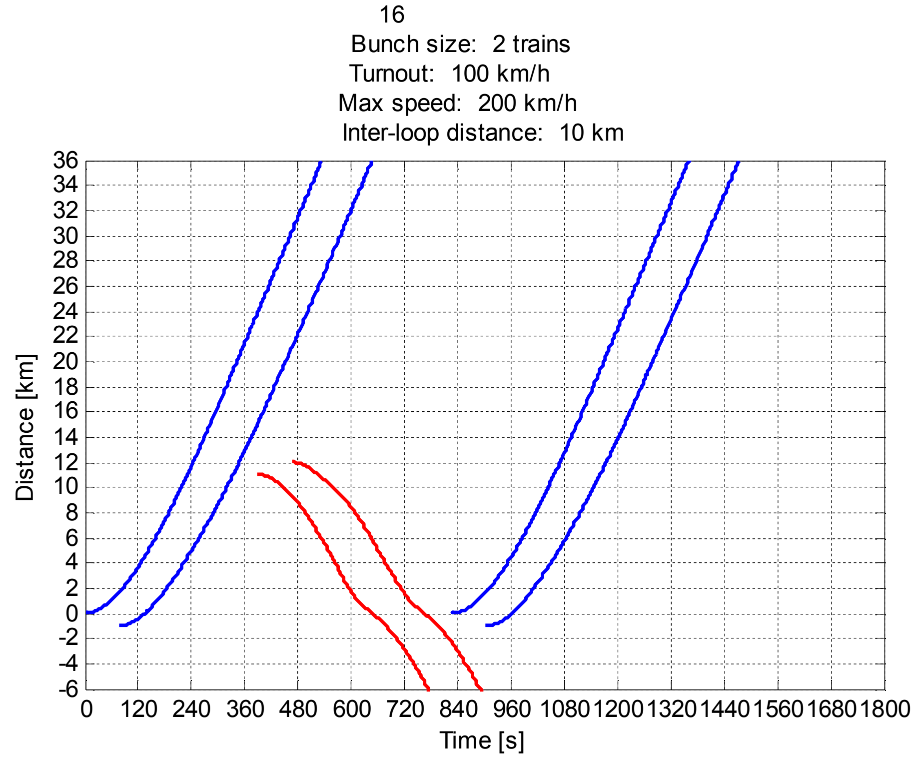
1320
1440
1560
1680
1800
Time [s]


16
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Distance [km]
36
34
32
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28
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24
22
20
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16
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4
2
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-2
-4
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120
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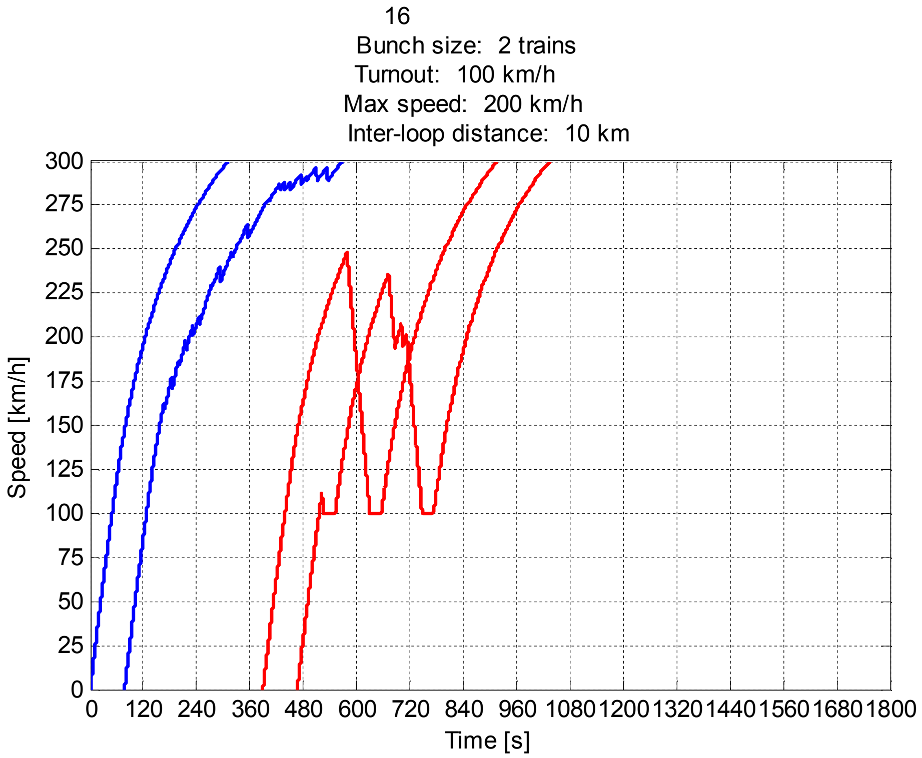
1200
1320
1440
1560
1680
1800
Time [s]


16
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
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120
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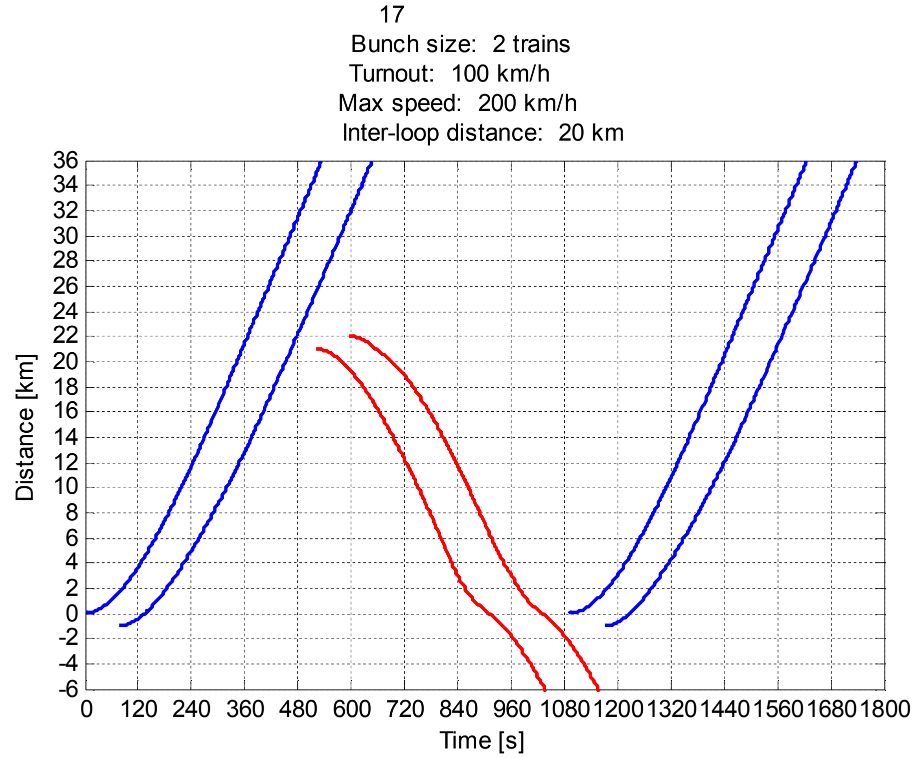
1080
1200
1320
1440
1560
1680
1800
Time [s]


17
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Distance [km]
Time [s]
36
34
32
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24
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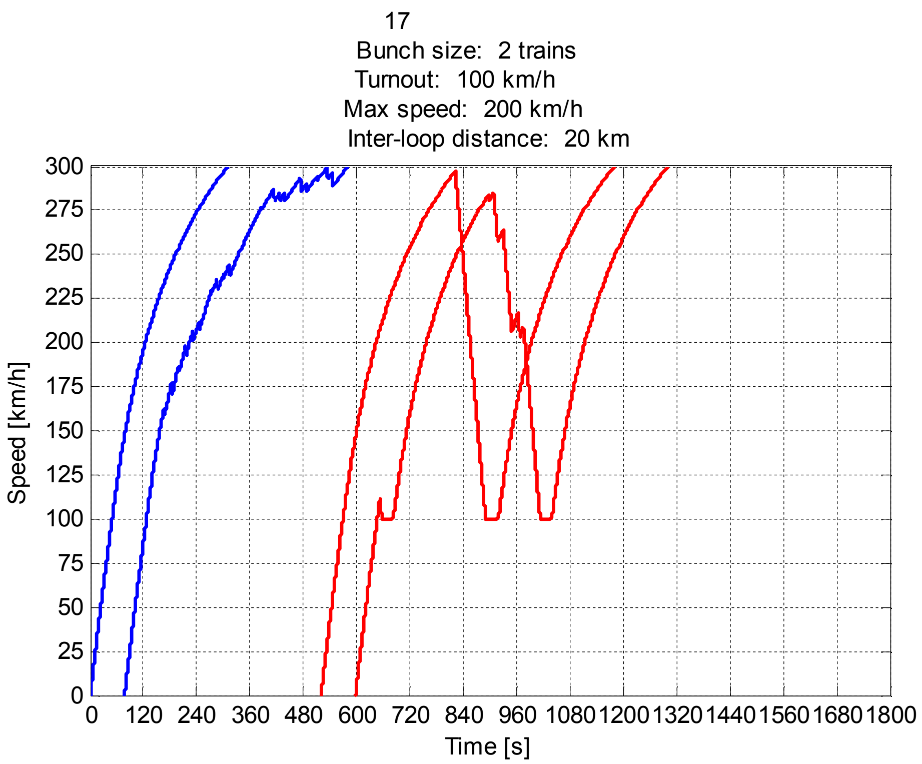
1440
1560
1680
1800


17
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Speed [km/h]
Time [s]
300
275
250
225
200
175
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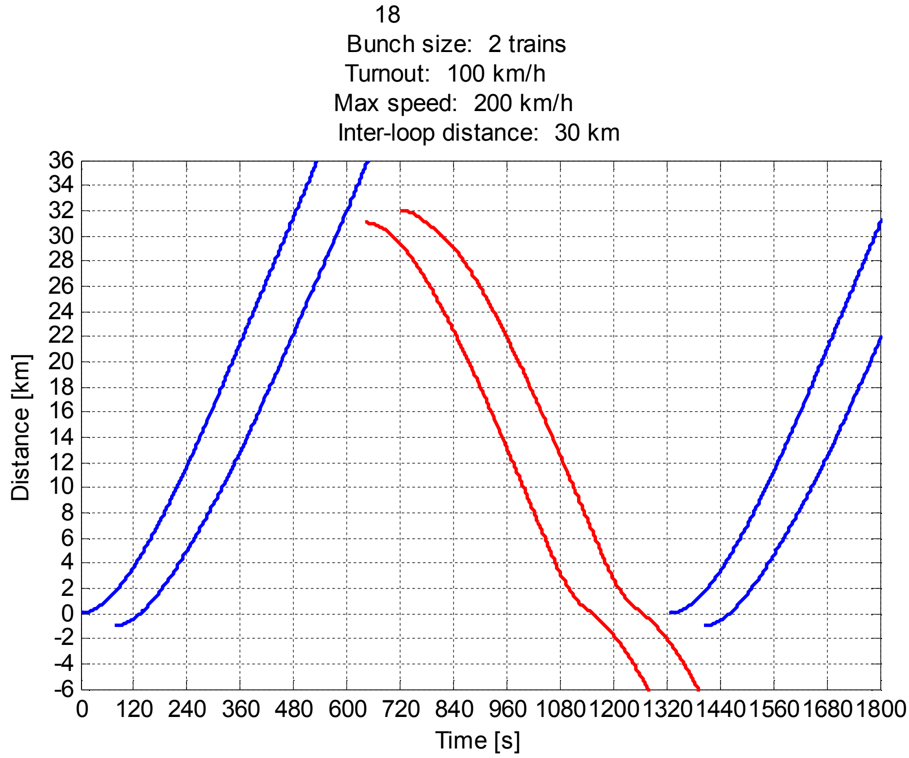
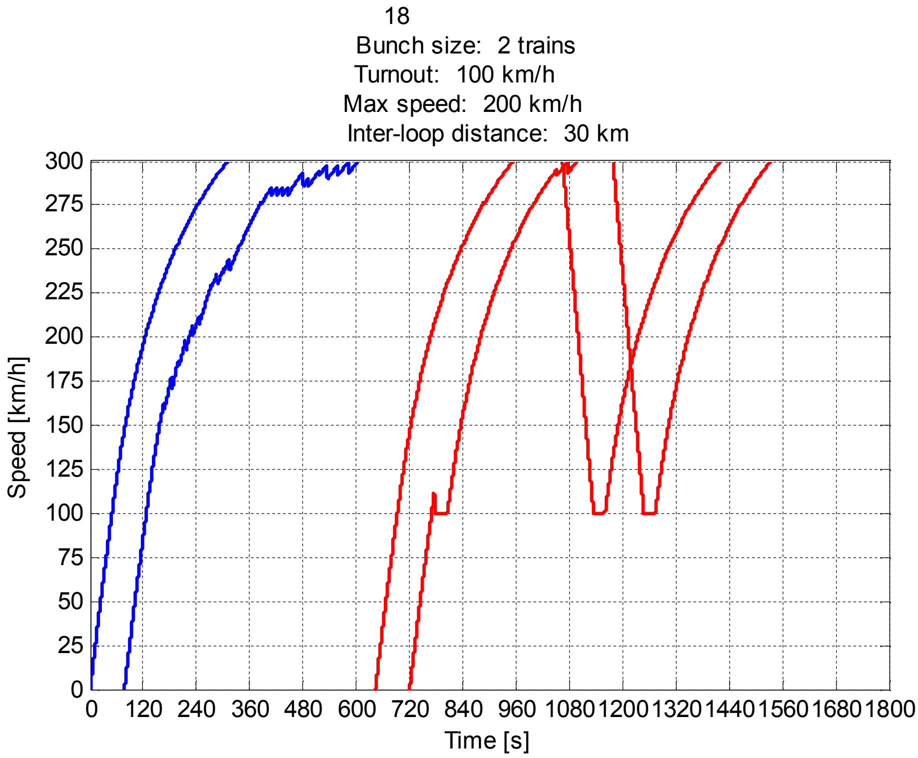
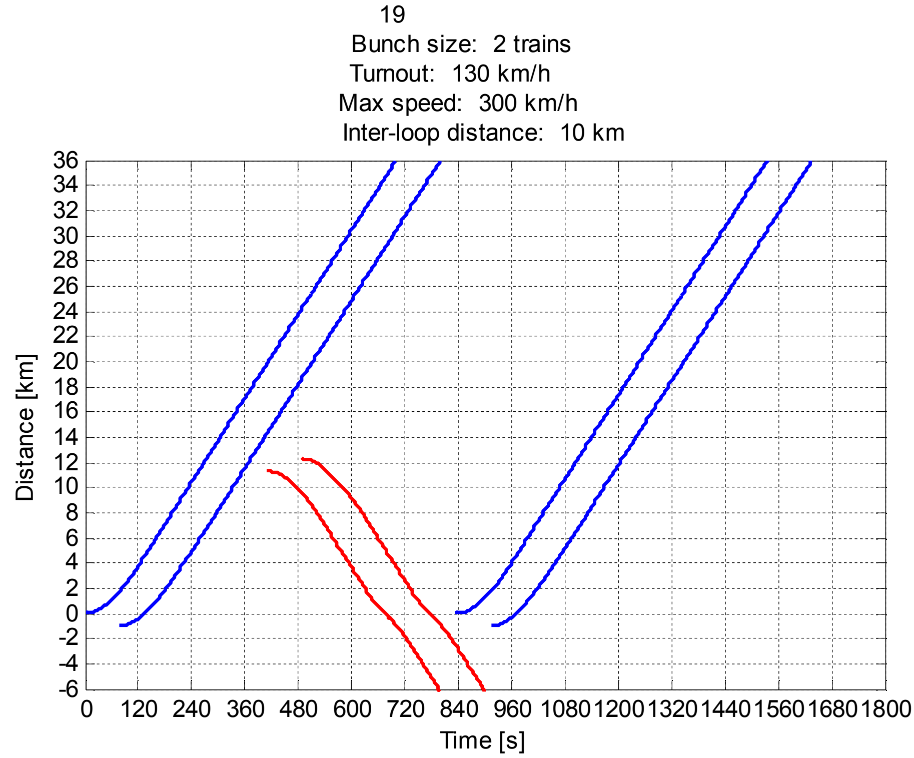
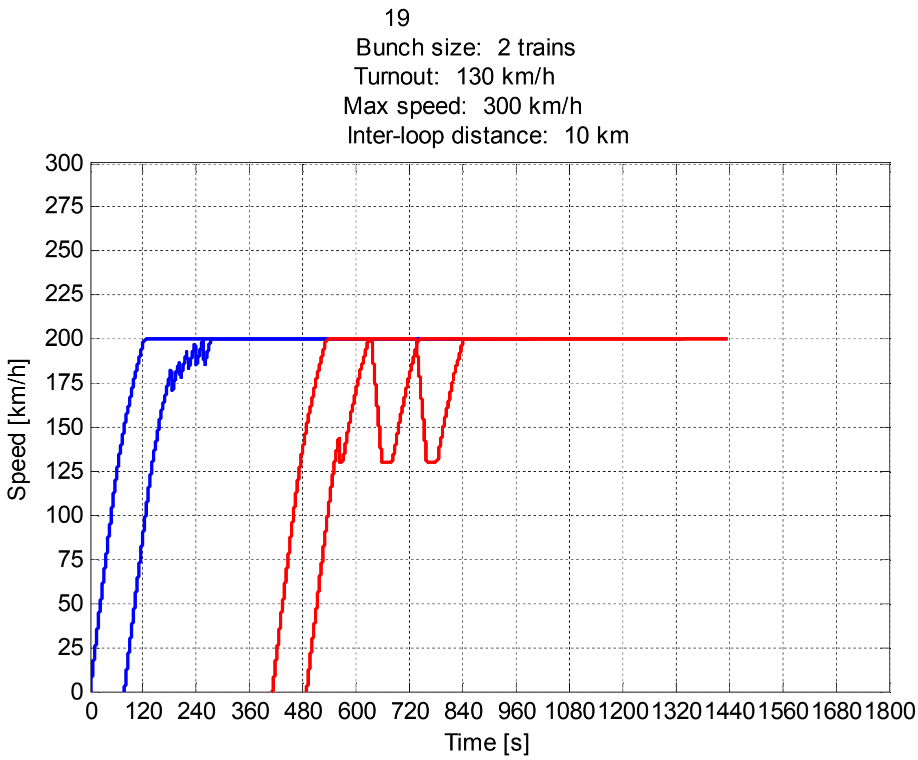


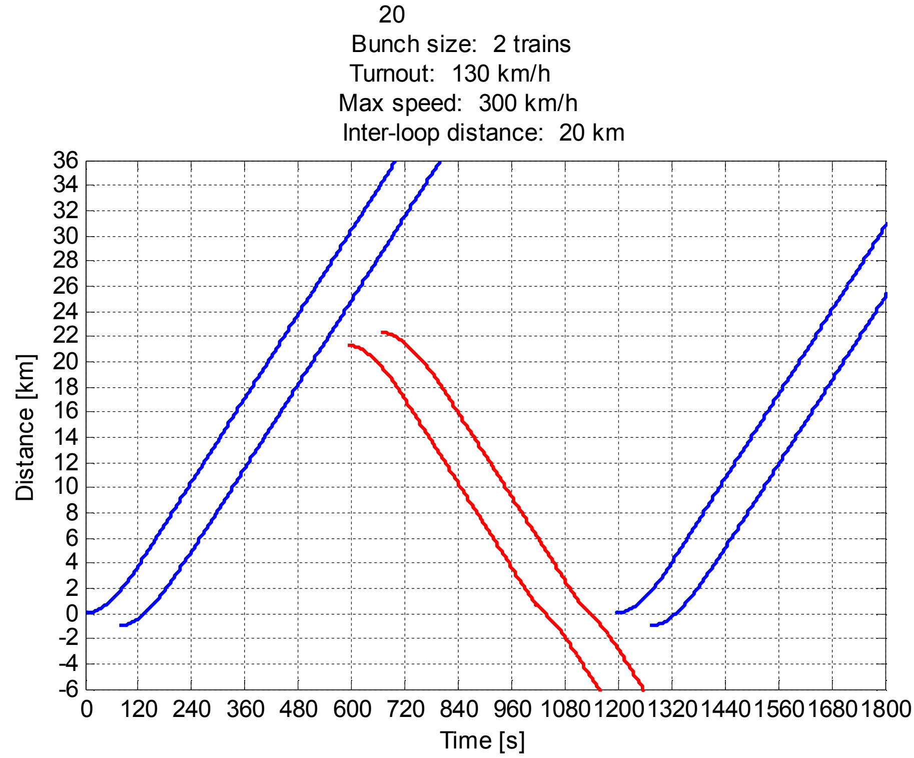
18
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Distance [km]
Time [s]

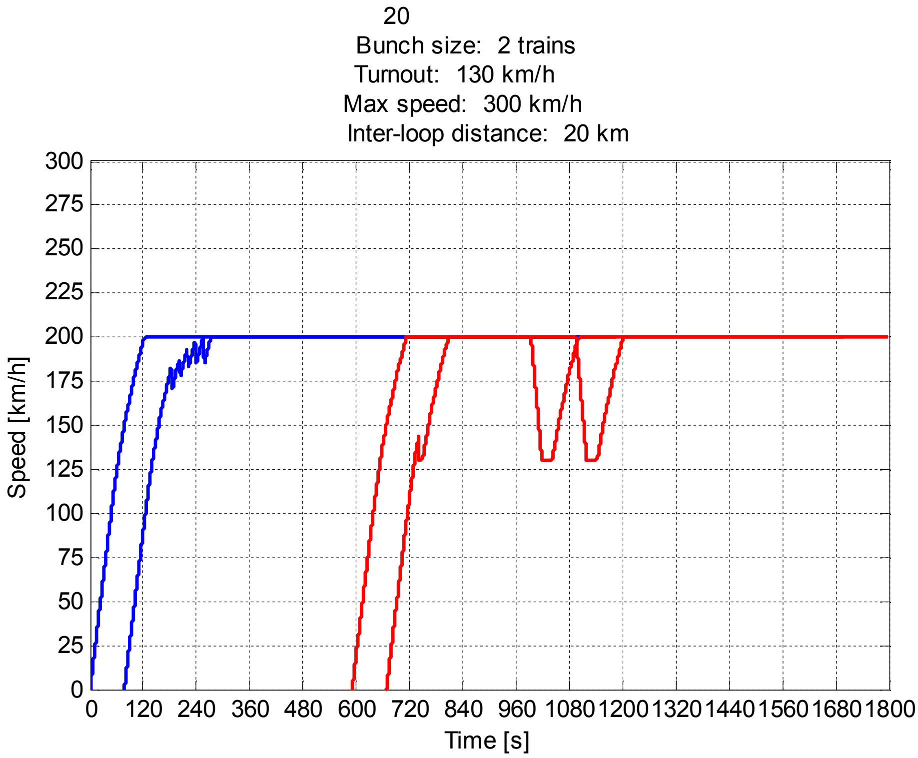


18
Bunch size: 2 trains
Turnout: 100 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Speed [km/h]
Time [s]

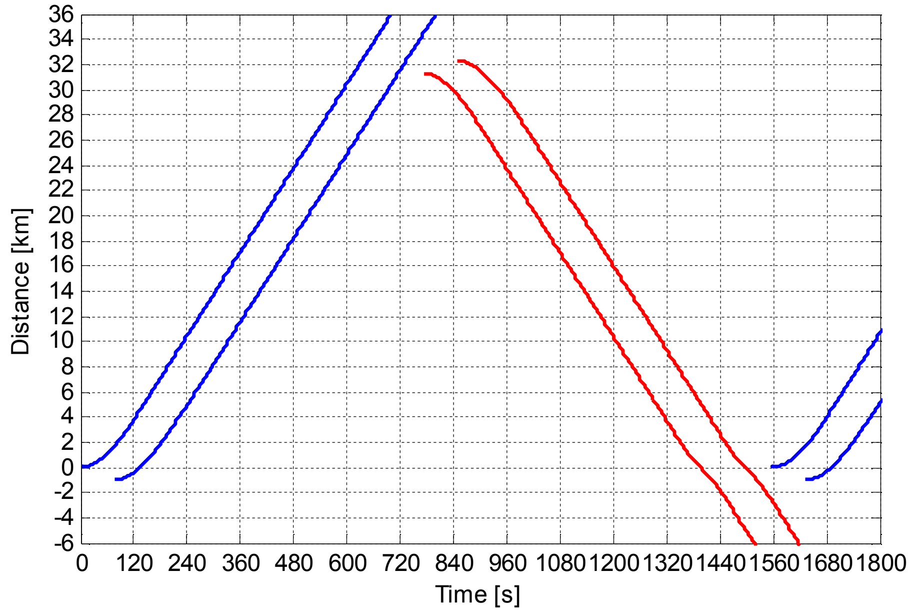

19
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


19
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 10 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]

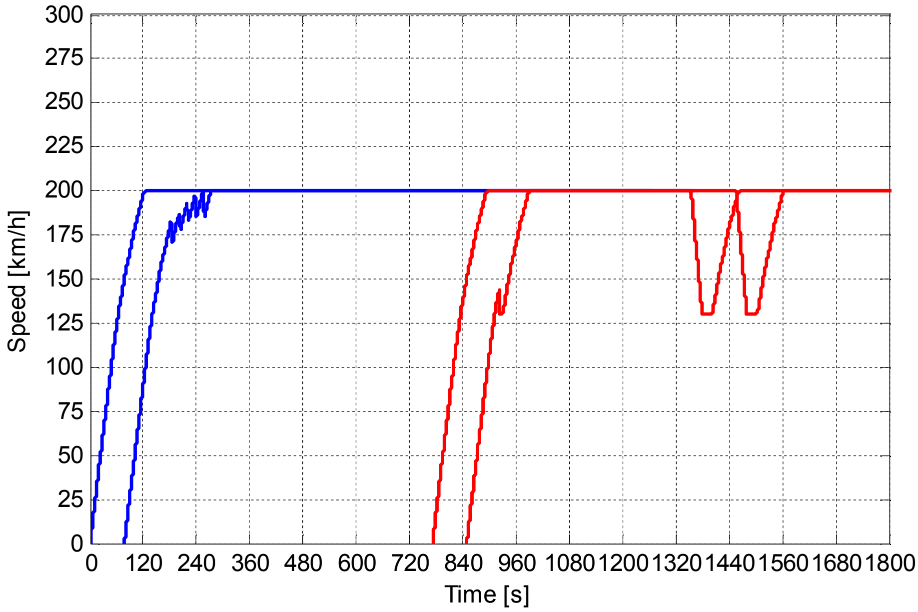

20
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
Time [s]

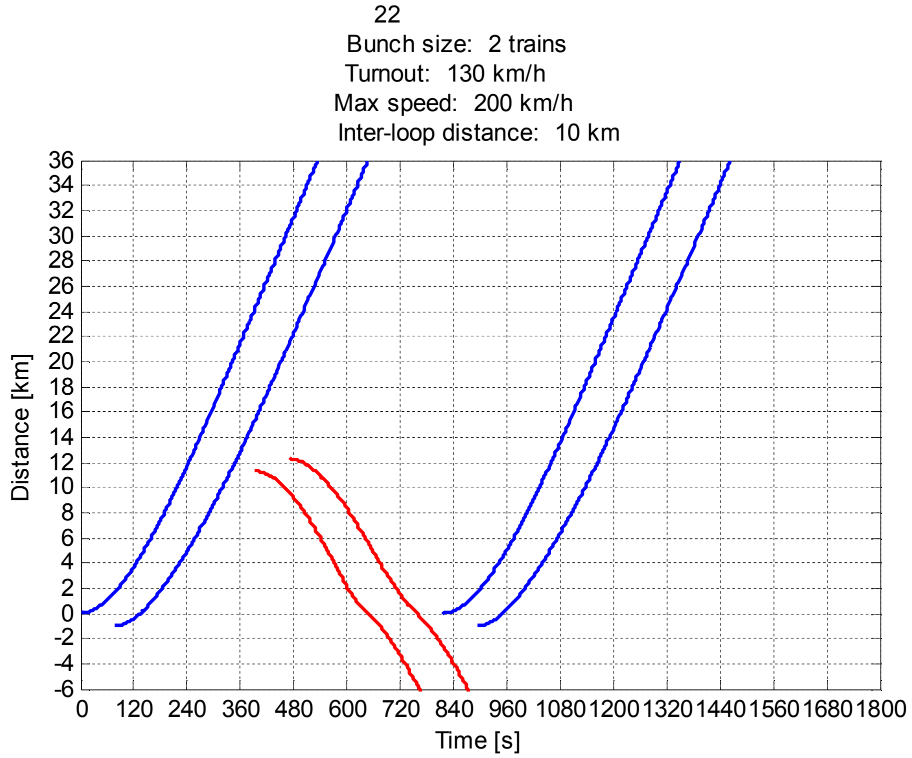

20
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 20 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
1560
1680
1800
Time [s]

21
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km



21
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 300 km/h
Inter-loop distance: 30 km




22
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Distance [km]
36
34
32
30
28
26
24
22
20
18
16
14
12
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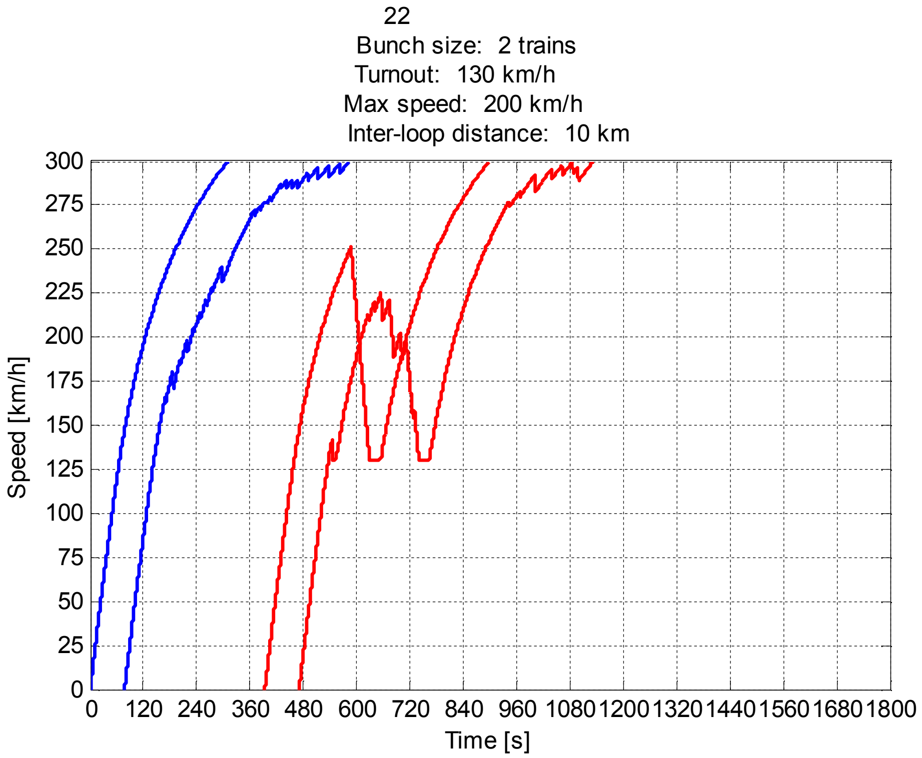
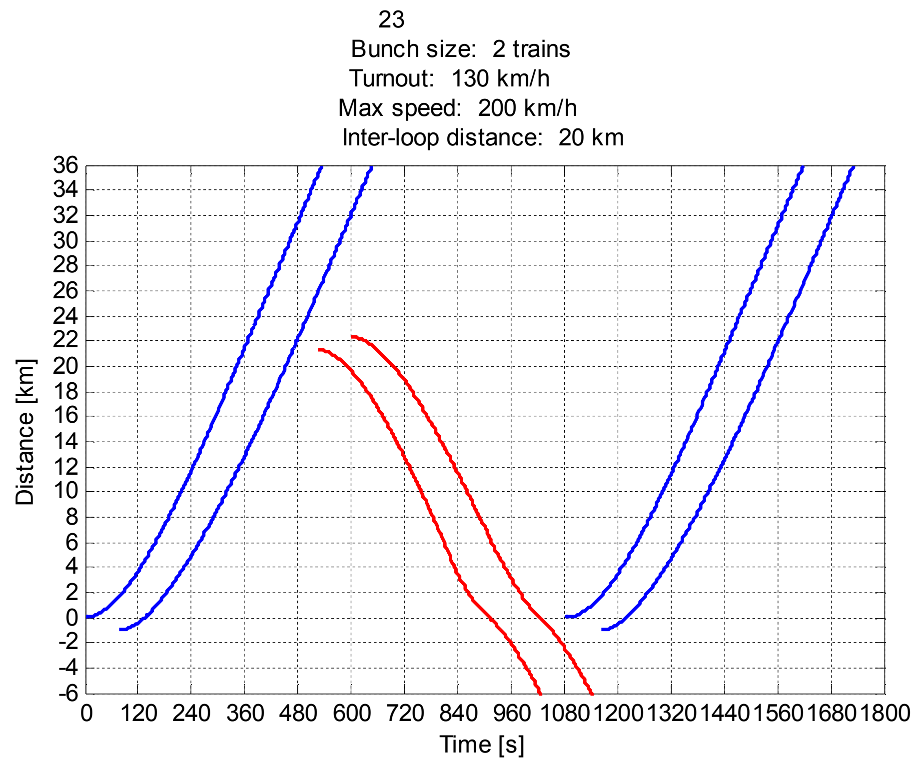
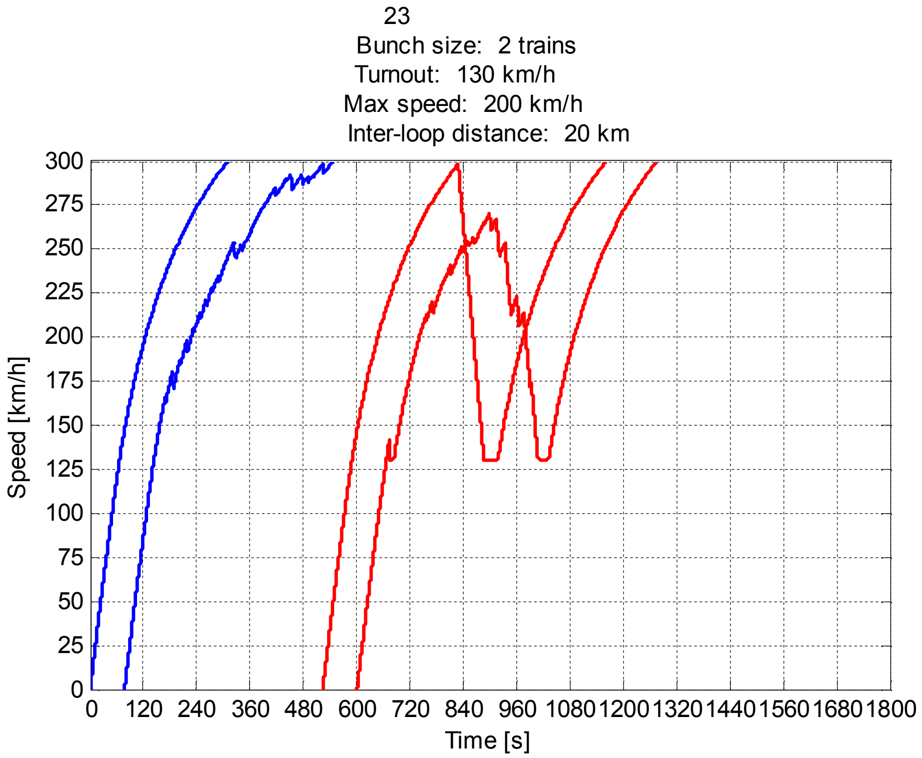
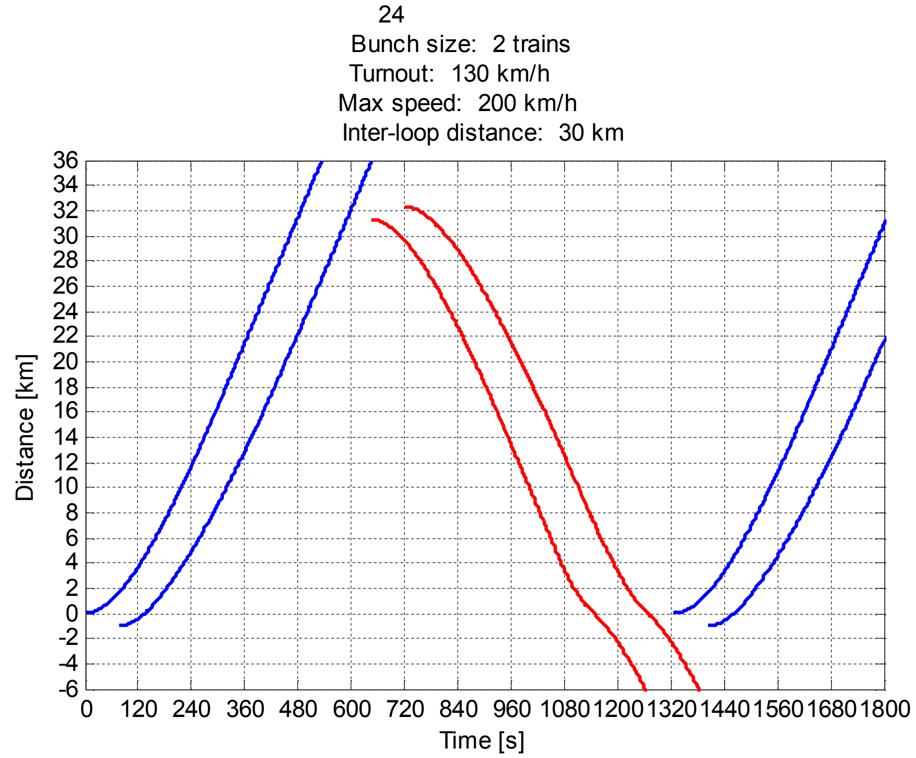
-2
-4
-6
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


22
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 10 km
Speed [km/h]
300
275
250
225
200
175
150
125
100
75
50
25
0
0 120 240 360 480 600 720 840 960 1080 1200 1320 1440 1560 1680 1800
Time [s]


23
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Distance [km]
Time [s]


23
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 20 km
Speed [km/h]
Time [s]


24
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Distance [km]
Time [s]
36
34
32
30
28
26
24
22
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18
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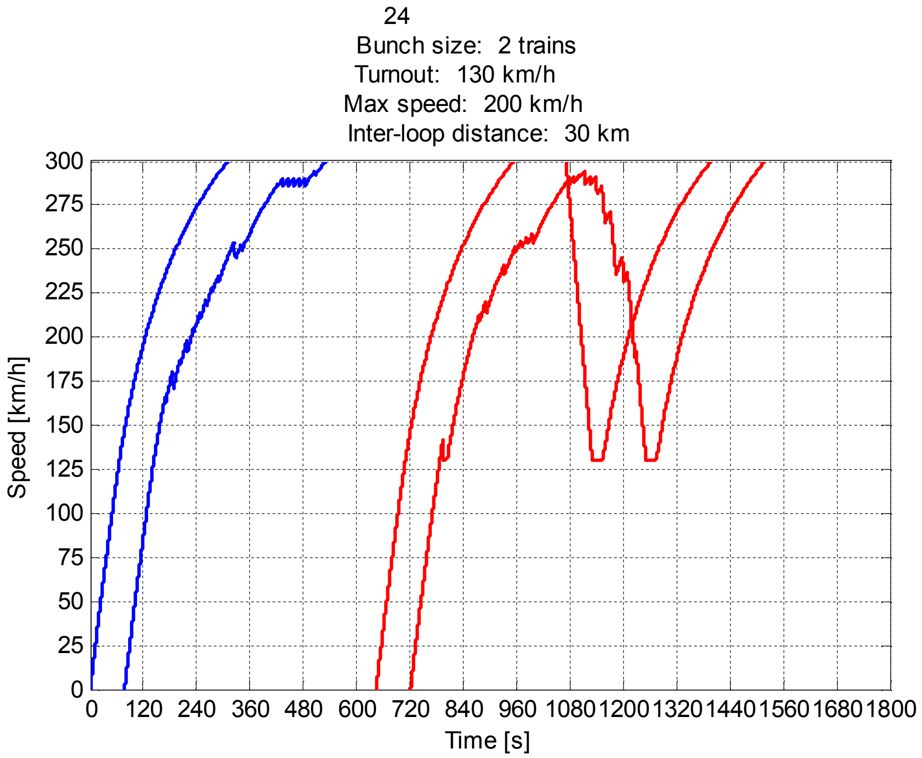
24
Bunch size: 2 trains
Turnout: 130 km/h
Max speed: 200 km/h
Inter-loop distance: 30 km
Speed [km/h]
Time [s]
300
275
250
225
200
175
150
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