Arrival time robustness of eco-driving strategies under two ATP systems

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SUMMARY

Under eco-driving the train driver needs to aim to arrive timely, i.e. exactly on the second of the planned arrival time, while using an energy-efficient driving strategy. In order to ensure this, the previous train at the arrival platform needs to clear the platform on time. Later clearing times can hinder the approach of a train, and can cause delays in arrival times. This study presents an apple-to-apple comparison between the Dutch NS'54/ATB Automatic Train Protection (ATP) system and ETCS L2, using the same End-of-Authority, speed restrictions, and block lengths. The focus of this study was the effect of the ATP on arrival times of eco-driving trains. In a computer simulation the approach of a test train under various degrees of platform clearing times was studied both for NS'54/ATB and ETCS L2. The results of this study show that arrival times of eco-driving trains are more robust under ETCS L2 than under NS'54/ATB, and that in addition to increased headway and capacity, ETCS L2 ensures that eco-driving trains experience less hinder from later platform clearing times of preceding trains than NS'54/ATB. Moreover, ETCS L2 makes it possible to obtain additional energy savings in a time table made for NS'54/ATB.

1 INTRODUCTION

In the coming decennia, the Netherlands plans to replace its legacy signalling system, NS'54/ATB with the proven technology of ETCS L2. NS'54/ATB is classified as a system with continuous track-to-train transmission of signal aspects by coded track circuits [1]. This type of ATP is used in several countries within Europe, and can be compared to TVM 300 in France; EVM in Hungary; and to a lesser extent to LS in Czech Republic; BACC in Italy; and ALSN in Russia, Ukraine, Belarus and the Baltic states.

The migration from NS'54/ATB to ETCS L2 is a much discussed subject, and various benefits are attributed to ETCS L2 over NS'54/ATB, such as enhancement of infrastructure capacity, safety, and interoperability (see e.g. [2]). It has already been shown that under ETCS L2 arrival times improve compared to NS'54/ATB during both disturbed and undisturbed operations [3]. However, this effect has not been studied yet in combination with eco-driving.

In this study the authors present the results of simulations in which eco-driving trains experience various degrees of hinder on approaching a station from a previous train at the arrival platform. The main contribution of this study is that during eco-driving the robustness of arrival times under ETCS L2 improve whilst the same level of energy-efficiency is maintained as under NS'54/ATB. The following section will explain the method used, after which the results are provided in Section 3. The paper ends with conclusions.

2 METHOD

This study is based on a previous study [4] where four driving strategies, the Minimum Time Train Control (MTTC), Energy Efficient Train Control (EETC), Maximal Coasting (MC) and the Reduced Maximum Speed (RMS) strategy, were compared on a number of Key Performance Indicators (KPIs) such as safety, timeliness, energy-efficiency, and workload of the driver. In this study the same driving strategies are used, and although the focus is on eco-driving, the non-eco-driving strategy MTTC is included as a reference. The test train is an Intercity (IC) [4], travelling on a trajectory with a length of 50 km (Figure 1). In the approach of the station there is a protected area of 1500 m before the final stop, in which a speed restriction of 80 km/h applies. The movement authority is given for this block as a whole.

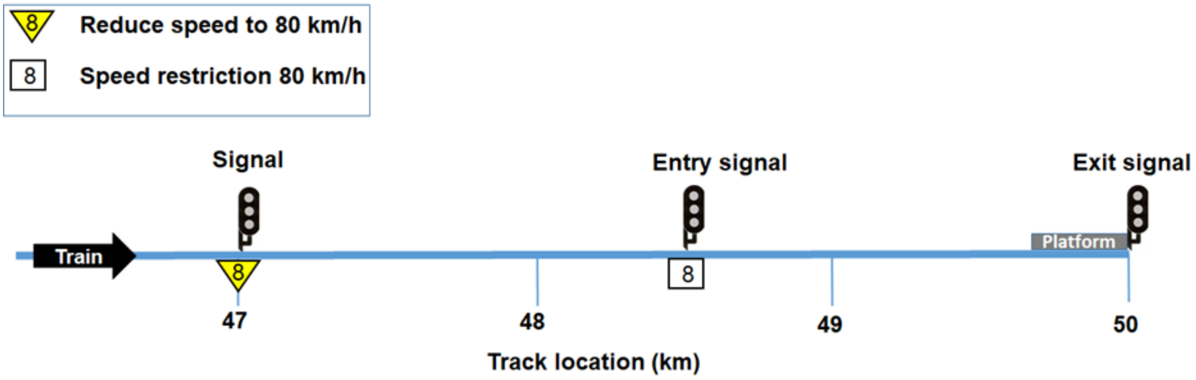

Figure 1: Approach station after a running track length of 50 km

The calculations in this study concentrate on the approach of the station where the test train experiences different degrees of obstruction from a preceding train at the arrival platform. We take the clearing moment of the entry signal as a reference. This is the time the train clearing time of the platform by the preceding train increased by the release and setup times.

2.1 Calculating arrival times

The input for the calculations of the arrival times are the speed and time of the test train at the signal at 47 km (see Table 1), and the entry signal clearing time of the preceding train (i.e. the time of improvement of the entry signal at 48.5 km). The speed and time at the signal passage are the result of the driving strategy. The signal passing time and entry signal clearing time are taken relative to the planned arrival time of the test train, and are therefore negative values. In this study arrival times of the test train were calculated with platform clearing times between -300 to 0 s.

NS'54/ATB and ETCS L2 runs are compared with the same driving strategies, and thus the same energy usage and approximately the same running time margin. This requires a correction for the scheduled running times due to the running time improvements of ETCS L2 over NS'54/ATB. Up until km 47, the speed profiles are the same for both ATP systems per driving strategy. Hence, the planned arrival times are increased for the NS'54/ATB with the value in the last column of Table 1.

A constant braking rate of 0.5 m/s² is assumed, without reaction times or speed dependence. In this way, the braking curve intervention in ETCS L2 is avoided, while conforming to minimal braking for NS'54/ATB. Acceleration is likewise taken at 0.5 m/s².

Driving strategy	Speed at 47 km (km/h)	Time at 47 km for NS'54/ATB (s)	Time at 47 km for ETCS L2 (s)	Time difference NS'54/ATB and ETCS L2(s)
MTTC	140	-329	-273	56
RMS	125	-196	-137	59
EETC	98	-201	-145	56
MC	85	-202	-153	49

Table 1:Speed and time at 47 km per driving strategy

2.2 Calculating headway and additional energy savings

We define the reference headway for trains running at maximal speed (comparable to the MTTC driving strategy) such that the sighting or reaction time is respected. The worst-case is then a timetable planned exactly with these headways. In practice, the scheduled running time will contain a running time supplement, and the planned headway will be larger than this minimum headway. In this study, a fixed time of 9 s was used as the sight time before the signal at 47 km for trains under NS'54/ATB. For NS'54/ATB, the train passes at 47 km 187 seconds before arrival. The headway thus is 196 s. Comparing this value with the NS'54/ATB time column in Table 1, one can infer that for tightly planned trains using eco-driving, the signal at km 47 will be passed at warning. For trains operating under ETCS L2, the sight/reaction time is taken at 10 s before the braking curve. For ETCS L2, the headway is 142 s, as a train arriving on line speed would require 132 seconds from 47 km to standstill.

The method of comparison in Section 2.1 retains the speed profile up to 47 km and running time margins. For a comparison with equal total running times, the running time supplement for ETCS L2 is increased with the additional time from the last column of Table 1. The running time margin then increases from 10 % to 14 %. Values for energy savings are obtained by interpolating the values for the reference scenario and the scenario with a running time supplement of 15 % from [4].

2.3 Obstruction classes

Depending on the driving strategy, and the platform clearing time the perspective of the driver on the arrival process differs. In this paper, a number of so-called obstruction classes were defined (see Table 2). These classes differ either in the way they appear to the driver (e.g. a signal that improves before there is an effect on the speed of the test train has no effect on the arrival time, but is experienced differently by a driver than a non-restrictive signal), or in the set of tasks the driver has to perform. In Section 3 arrival times will be grouped in obstruction classes.

Note that under NS'54/ATB the driver is prohibited from accelerating after the signal improves. That is the reason why only NS'54/ATB has an obstruction class C, with a prolonged speed of 40 km/h, whereas this class is not applicable under ETCS L2.

Id	Obstruction class	NS'54/ATB	ETCS L2
0	No restrictive signal	Entry signal already clear. No Signal Passed at Warning (SPAW).	
A	No speed restriction	Entry signal improves at v_train > 80 km/h. Driver approaches platform similar to ATB 0	Entry signal improves before the braking curve for the stop in rear of the entry signal is reached. Driver maintains speed before braking to 80 km/h
B	Limited speed restriction	Entry signal improves at 40 km/h < v_train < 80 km/h. Driver maintains actual speed.	Entry signal improves during braking to 80 km/h. Driver maintains actual speed and then brakes to 80 km/h
C	Prolonged speed restriction (40 km/h)	Entry signal improves at v_train = 40 km/h. Driver maintains speed of 40 km/h for a prolonged period of time before end brake	-
D	Near stop	Entry signal improves at v_train < 40 km/h. Driver accelerates to 40 km/h and maintains speed before end brake.	Entry signal improves during end brake in rear of the entry signal. Driver accelerates to 80 km/h and maintains speed before end brake.
E	Full stop	Full stop in rear of the entry signal. After entry signal improves the driver accelerates to 40 km/h, and maintains speed before end brake	Full stop in rear of the entry signal. After entry signal improves driver accelerates to 80 km/h and maintains speed before end brake

Table 2: Obstruction classes

Figure 2 shows the speed profiles for the obstruction classes under NS'54/ATB. The obstruction classes are labelled ATB 0 (the NS'54/ATB obstruction class with id= 0 see Table 2) to ATB E (the NS'54/ATB obstruction class with id= E see Table 2). In Figure 3 the speed profiles for the obstruction classes under ETCS L2 are shown. The obstruction classes are labelled L2 0 (for the ETCS L2 obstruction class with id= 0, see Table 2) to L2 E (the ETCS L2 obstruction class with id= E, see Table 2)

In order to make the differences between the obstruction classes in Figure 2 and Figure 3 explicit, a train speed of 110 km/h at location 47 km was chosen.

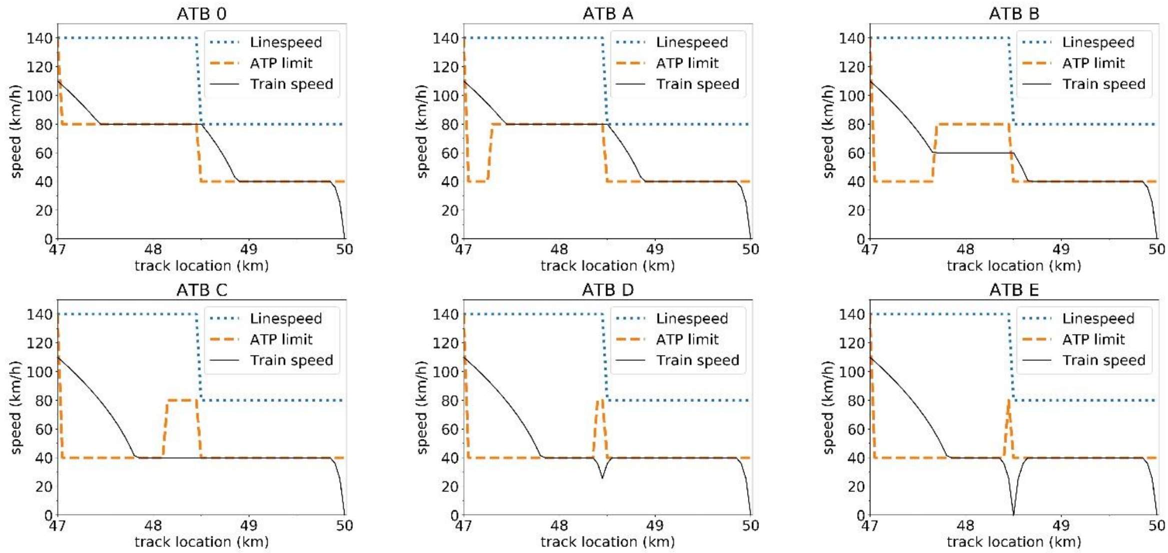

Figure 2: Speed profiles for obstruction classes under NS'54/ATB

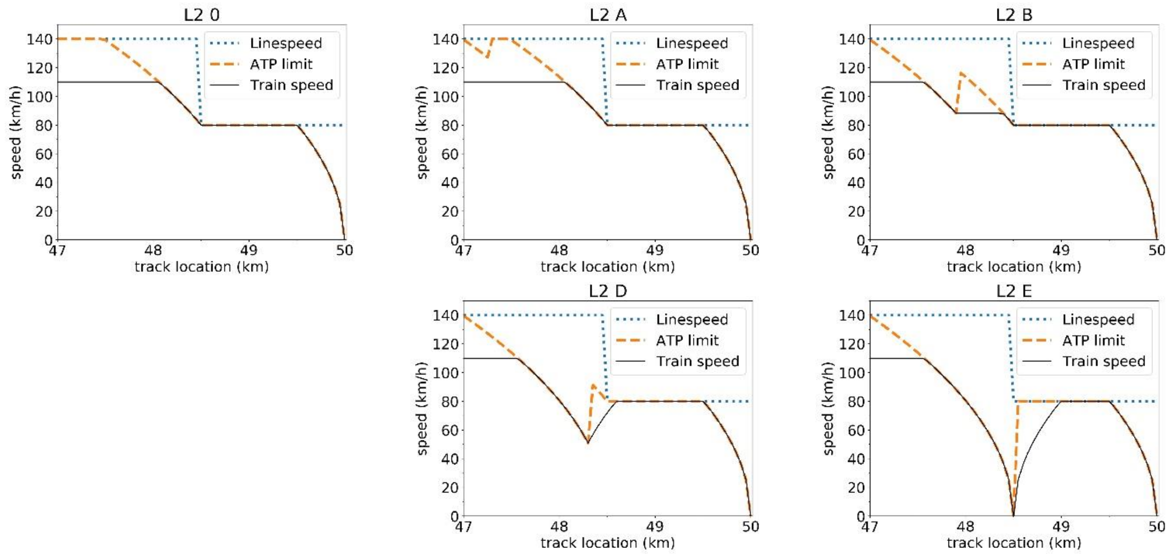

Figure 3: Speed profiles for obstruction classes under ETCS L2

3 RESULTS

The results of the calculations are presented in this section. The values are presented in Figure 4 and Figure 5. Values from the calculations at specific points in the graphs are presented in the text. In general the resulting graphs of this study (see Figure 4 and Figure 5) show that for high negative platform clearing times (left side of the graphs) the test train does not experience hinder from the previous train at the platform, whereas when the platform clearing times are nearer to zero (right side of the graphs) the chance of a delay, and a near or full stop in rear of the entry signal (obstruction class D or E) increases.

3.1 Comparison using NS’54/ATB running time margin and energy use for ETCS L2

In Figure 4, and Figure 5 the arrival time with respect to the planned arrival time (along the vertical axis) is presented as a function of the clearing time of the entry signal (time with respect to the planned arrival time, along the horizontal axis). The running time margin is 10% for all driving strategies. Obstruction classes are shown with markers. Figure 4 represents speed profiles for an NS'54/ATB time schedule, and Figure 5 displays speed profiles for a ETCS L2 time schedule.

Starting with the MTTC case in Figure 4a, one observes that for clearing times earlier than the NS'54/ATB headway, the train arrives 138 s before the planned arrival time (the values at the left-hand side of the curve). For trains where the entry signal clears after the train has come to a full stop (obstruction class E, on the right-top part of the curve), the arrival time is a fixed offset time after the platform clearing time. At a clearing time of the NS'54/ATB headway of 196 s (the blue vertical line), the graph shows that the train arrives 31 s early.

Looking at the EETC case In Figure 4c, one observes that for clearing times earlier than the NS'54/ATB headway, the train arrives exactly on time (left-hand side of the curve). For trains where the entry signal clears relatively late (e.g. 60 s), the train arrives just as with MTTC (right-top part of the curve). For a large range of clearing times (-165 s until -100 s, obstruction class C), one observes that the train arrives with a delay of 57 s. In the obstruction class C, the clearing time of the entry signal does not change the arrival time, as the driver is not allowed to accelerate towards a signal at warning. For reference, the MTTC arrival time (Figure 4a) is plotted as well. One observes that a train aiming to be on time using eco-driving under NS'54/ATB will arrive later than a train using MTTC. Eco-driving trains with a planned interval close to the headway under NS'54/ATB are at a disadvantage, since small delays with respect to heading will occur frequently.

For MC under NS'54/ATB (Figure 4d), there is a small delay even if the previous train clears the signal exactly at the time of the NS'54/ATB headway (this was already noted in [4]). There is an even longer range of clearing times than for MTTC in which a delay of 65 s is incurred. Trains that would not have used eco-driving would have lower delays. For RMS (Figure 4b) this disadvantage is less pronounced. The energy savings of RMS, however are much smaller than for either MC or EETC [4].

The ETCS L2 graphs in Figure 5 show a simpler picture. Note that the ETCS L2 minimum headway is shorter than the NS'54/ATB minimum headway (as a reference, the NS'54/ATB headway is also shown in Figure 5). As for NS'54/ATB, it is best to start the observations with MTTC in Figure 5a. For very late clearing times (right-top part of each of the curves), one observes that the train arrives 39 s earlier than under NS'54/ATB. One observes that an MTTC train (Figure 5a) at the ETCS L2 headway of -142 s (the orange vertical line) arrives 16 s ahead of the planned arrival time.

Looking at the EETC case in Figure 5c, one observes that for clearing times between -300 s (or smaller) and -120 s (41 s past the ETCS L2 headway time), the train arrives exactly on time. For clearing times between -120 and -65 s (obstruction classes B and D), an eco-driving train arrives earlier than an MTTC train. The reason Is that for ETCS L2 there Is no obstruction class C (a long period during which the maximum speed is 40 km/h). For a train running under ETCS L2, eco-driving therefore increases the robustness of the operation.

The differences between the arrival times of the different eco-driving strategies (Figure 5b, 5c, and 5d) are small for ETCS L2. Therefore, in contrast to under NS'54/ATB, arrival time robustness plays no role in determining which eco-driving strategy should be used under ETCS L2.

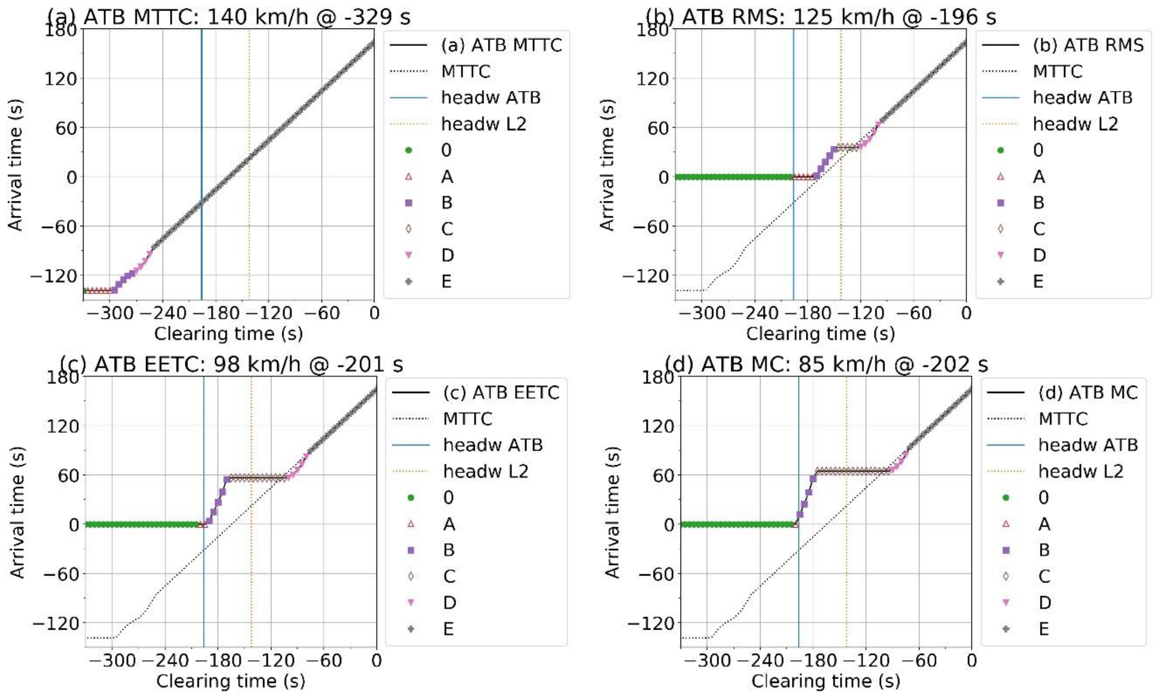

Figure 4: Arrival times under NS'54/ATB (a) MTTC, (b) RMS, (c) EETC, (d) MC. Markers show the obstruction classes (ATB 0 to ATB E, see Figure 2). headw ATB= headway NS'54/ATB. Headw L2 = shows the headway ETCS L2 as a reference.

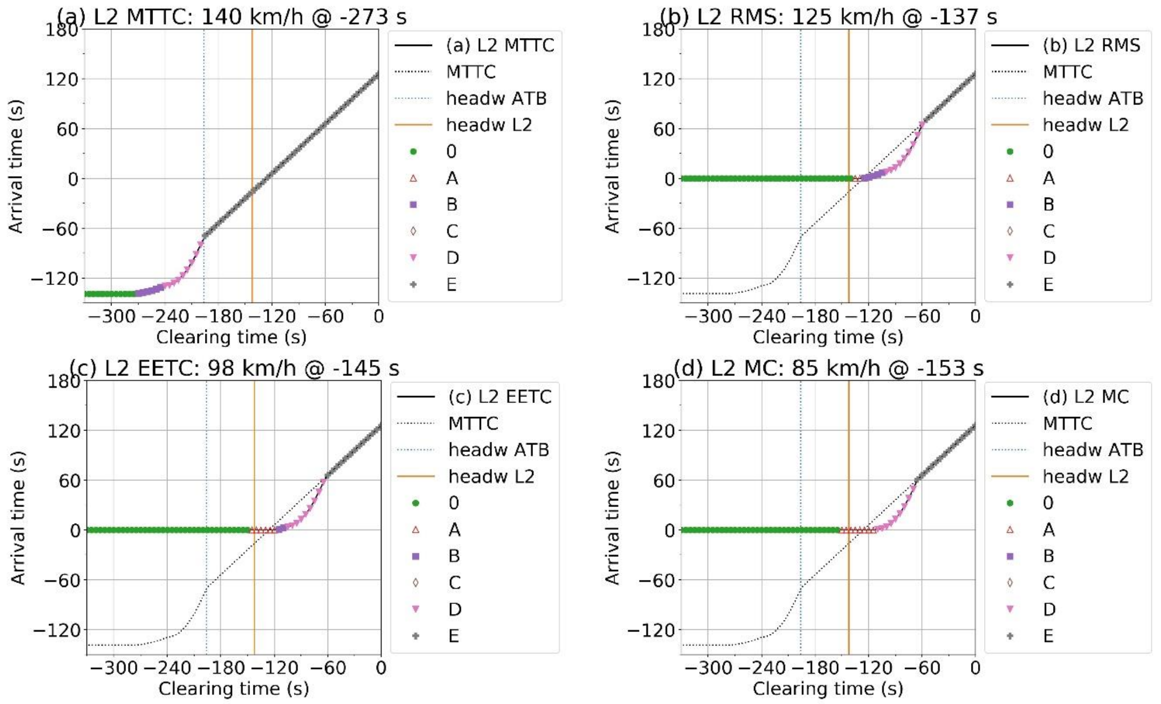

Figure 5: Arrival times under ETCS L2 (a) MTTC, (b) RMS, (c) EETC, (d) MC. . Markers show the obstruction classes (L2 0 to L2 E, see Figure 3); headw ATB= headway shows the NS'54/ATB headway as a reference; headw L2 = headway ETCS L2..

3.2 Comparison using NS'54/ATB time table and headway for ETCS L2

In Section 3.1 an apple-to-apple comparison between NS'54/ATB and ETCS L2 was carried out, using the same block lengths and the same energy usage for both ATPs by assuming an equal remaining running time margin at the end (and thus discarding the shorter running time of ETCS L2 operation). In this Section, the NS'54/ATB timetable and headway is maintained, also for trains under ETCS L2. The number of seconds given in the first column of Table 3 are added to the timetable for both NS'54/ATB and ETCS L2. For NS'54/ATB, the running time margin remains 10 %, the speeds at 47 km remain the same as in Table 1. The energy savings remain the same as in [4]. With the added time, the running time margin for ETCS L2 then becomes 14% instead of 10% for NS'54/ATB. It is assumed that the driver knows ETCS L2 will be used near the station. This then leads to a lower speed at 47 km and higher energy savings (see Table 3). For the MC case, the speed at km 47 drops below the speed limit of 80 km/h past km 48.5. The additional energy savings are lower than for the other driving strategies, although MC remains more energy-efficient than RMS.

Driving strategy	Extra running margin ETCS L2 (s)	v at 47 km at 14 % running time margin (ETCS L2) (km/h)	Energy savings at 14 % running time margin (ETCS L2)	Additional energy savings	Energy savings 10 % (NS'54/ATB) (see [4])
MTTC	56	140	0%	0.0%	0%
RMS	59	119	26%	5.2%	21%
EETC	56	93	30%	5.1%	25%
MC	49	79	27%	1.9%	25%

Table 3: Passing speed, energy savings compared to MTTC, and additional energy savings compared to NS'54/ATB due to the increase in running time margin from 10 to 14 % by using ETCS L2.

If the headway of the planning (and thus the line capacity) is still based on NS'54/ATB, the headway in Figure 5 should be taken from the line "headway ATB" rather than "headway L2". The preceding trains can have 55 s more delay than with the L2 planning before the test train gets affected. For example at a clearing time of -120 s (73 s after the planned NS'54/ATB headway), a train driving under NS'54/ATB will be delayed by 60 s, while a train under ETCS L2 is still on time.

4 CONCLUSION

Under NS'54/ATB all eco-driving trains will experience more hinder from preceding trains at the arrival station, resulting in later arrival times. This might discourage train drivers from applying an eco-driving strategy. For RMS this effect is slightly smaller than for either MC or EETC. This disadvantage will disappear under ETCS L2 where all eco-driving strategies will arrive approximately at the same time.

Compared to the Dutch NS'54/ATB the installation of ETCS L2 in the approach of stations will have a positive effect on eco-driving trains. In an apple-to-apple comparison of these two ATPs, this study shows, that the robustness of arrival times of eco-driving trains improves under ETCS L2. Since eco-driving trains will experience less hinder from platform clearing times of preceding trains that are still at the arrival platform.

If the time table is still based on NS'54/ATB then shorter headways, a reduction of running times, and extra energy-savings can be gained under ETCS L2. Drivers should however be aware of the additional running time, otherwise trains will arrive ahead of time, and could conflict with departing preceding trains with a delay of a few seconds.

When the time table is adjusted to ETCS L2, the arrival times of eco-driving trains will remain robust. Optimizing block lengths could lead to shorter headways and possibly even more arrival time robustness. However, this is not the subject of this paper.

Since the MTTC driving strategy usually arrives ahead of time in unhindered situations, train drivers applying this strategy will manage to arrive on time, despite later platform clearing times. However, the workload will increase significantly in hindered situations, because the driver will often be obliged to come to a full or a near stop (obstruction class D and E) in the approach of the station or yard.

5 REFERENCES

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