This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no. 826087 (M2O)

Deliverable D 3.3
TrainDy simulations for experimental tests

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Report contributors		
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Summary

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1. Executive Summary

This deliverable takes up on the input of the Sensitivity analysis performed in D2.2 enabling to identify the most relevant parameters impacting the Longitudinal Train Dynamics (LTD). It is based also on the general simulations performed in D3.1, where different train configurations, in terms of hauled mass, train length, number of Traction Units (TUs), and operational conditions have been utilized to simulate LTD, considering different radio technologies.
In this deliverable, the focus is to study the LTD of the DPS test demonstrator envisaged to run on a predetermined infrastructure characterized by slopes up to 27‰, curves and some sections where radio connection has dead spots. The methodology involves the study of 4 train families:

- The train family without DPS and with 2 TUs placed at each end of the consist: it is also called reference (REF) train family.
- The first DPS train family with 2 TUs placed at each end of the consist.
- The second DPS train family with 2TUs: one placed in front and a second one in the middle of the consist.
- The third DPS train family with three TUs: two being at each end of the consist and the third one placed in the middle of the consist.

All these TUs are connected by a radio communication solution based on LTE. The objective is to compare the LTD simulation results of the DPS train families against the reference (REF) train family (without DPS), assumed safe, in different operating conditions. Simulations are based on train families randomized in terms of wagon type and load distribution, within boundaries given by existing trains running on that track, according to DB Cargo train database.
DPS trains are studied in "nominal" conditions (e.g. with proper radio communication, §8.1) and in "degraded" conditions (e.g. in case of radio communication loss or other failure of the DPS system). Similar conditions are replicated for REF trains, to make a proper comparison. Since the emphasis of the TrainDy simulations is on the in-train forces, ten different families of train operations are identified, jointly with FR8RAIL II Partners by means of an Experts estimation, to compare LTD of REF and DPS trains, in conditions in which it is possible foreseeing high in-train forces. Simulations are performed both on planar track (§8 and §10) and on up/down hill track (§9) in positions characterized by high variation of slope, in a parametric way.
Among the different simulations, also the conditions in which the Driver on a guided TU is requested to intervene, because DPS is not able to detect the pressure drop of 0.2 bar in case of radio communication loss, are simulated in §10, to replicate a scenario of possible occurrence during the tests, even if with a low probability.
Finally (§11), some simulations are performed to show how to improve some parameters of DPS system, relevant for in-train forces.
As a conclusion the DPS trains studied are generally better than the reference trains and can still be improved by some technical and operational adaptations: some of them will be tested by FR8RAIL II Partners during the experimental tests.

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2. Abbreviations and acronyms

Abbreviation / Acronyms	Description
TU(s)	Traction Unit(s)
LTD	Longitudinal Train Dynamics
LCF	Longitudinal Compressive Forces
LTF	Longitudinal Tensile Forces
DPS	Distributed Power System
EB	Emergency Braking
FTB	First time Braking, target pressure in brake pipe is 4.5 bar
ED	Electro-Dynamic braking
T-EB	Full traction followed by an emergency braking
DBV	Driver's brake valve
LWL	Train consist in which the active TU are at the beginning and at the end. TU in the middle is not active
LWLW	Train consist in which the active TU are at the beginning and in the middle. TU at the end is not active
LWLWL	Train consist in which all TU are active
UD/DF	They indicate two points on the track around which specific tests are performed, see Fig. 1
C.L.	In some graphs, it indicates the starting instant of radio communication loss
TRL	Technology Readiness Level

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3. Background

The present document constitutes the Deliverable D3.3 "TrainDy simulations for experimental tests" in the framework of the TD5.4, of IP5.

This deliverable follows the simulation studies performed in D2.2 and D3.1 and compares the Longitudinal Train Dynamics (LTD) of a reference system, i.e., a train family already admitted to the traffic, against a new system, a train family equipped by the DPS system, in different operative conditions.
The railway track used for the tests has been decided by FR8RAIL II Partners and it is in the area between Kronach and Probstzella, with slopes up to 27‰.
At the time of the preparation of this deliverable, the final train consist has not been yet decided, therefore, the analysis here presented is based on statistic virtual trains. When the train consist will be fixed, according to the availabilities of FR8RAIL II Partners, the train operations of the test demonstrator will be simulated, and the results are part of the D3.2. For this reason, 100 statistic trains are simulated in different conditions to see the effect of DPS solution in terms of in-train forces and to identify possible fields of future optimization of DPS solution.

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4. Objective/Aim

This document analyses two train families: a "reference system", i.e., train family that is already admitted to the traffic on the track selected for the tests; a "new system", i.e., the same train family in where the Traction Units (TUs) are equipped by the DPS system. These two train families are compared in terms of Longitudinal Train Dynamics (LTD) in different operative conditions: i.e., different train operations or manoeuvres and different track positions. In this deliverable too, as in D3.1, the relative approach envisaged by UIC Leaflet 421 is followed. In this deliverable, the compared trains are identical except for the "technology" employed on the TU and for the number of "active" TU, i.e., a TU having its electronic part habilitated, otherwise it behaves as a wagon. This means that a "one to one" comparison is possible to highlight the effect of the new DPS technology on LTD.

Therefore, just considering the LTD, the aim of this deliverable is to compare the reference system against the new system to find out the conditions under which the new system is better (or worse) than the reference system. In case the longitudinal compressive forces of new system are worse than the reference system (this happens only in some "degraded" mode), it will be shown that these forces are like those occurring in reference system (in "nominal" mode).

Out of the scope of this deliverable, this relative approach can be used to increase the train length / hauled mass to reach the "same" LTD of the trains considered safe (i.e., already approved to traffic).

Another aim of this deliverable is to provide to FR8RAIL II Partners a consistent support to decide the operational scenarios and the positions along the track to use for each train operation. Final simulations are added in D3.2 when the precise train consist will be defined, according to the availability of wagons, and the simulation plan will be agreed.

Third aim of this deliverable is to simulate some alternative parameters options of DPS and then to verify (when the tests are performed) the agreement (or not) among the numerical results and experimental measurements. In this way, simulations can be used to improve the DPS parameters.

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5. Train Consists

The reference train family is made of 100 trains generated according to UIC Leaflet 421. Train database has been provided by DB Systemtechnik, considering trains currently running on the railway track between Kronach and Probstzella. The wagons used for the demonstrator will be a sub-set of those used for this deliverable. The train family is made of trains having length between 720 and 740 m (TU included) and hauled mass between 1800 and 1850 ton. Each train has three TU: one at the beginning, another at the end and the third in the middle. According to the position of active TU, following nomenclatures are used (when the TU is not active it behaves as a wagon):

- LWL indicates a train consist in which the active TU are at the beginning and at the end. TU in the middle is not active. Pictogram is , for reference system and it is 

for DPS system.
- LWLW indicates a train consist in which the active TU are at the beginning and in the middle. TU at the end is not active. Pictogram is 

.
- LWLWL indicates a train consist in which all TU are active. Pictogram is 

Only difference between LWL, LWLW and LWLWL is the number and the position of active TU: this allows to highlight the effect of DPS and the position and number of active TU. Reference train family and DPS train family are compared by direct comparison of the LCF and LTF, without considering the permissible LCF or LTF, since the types of wagons and their payloads are the same changing from reference system to DPS system, for each train.
Having one TU at each end, the considered train composition allows a quick operation from starting location "A" to destination "B" and from "B" to destination "A".
Since it is not easy to foresee the number of wagons equipped by cast iron shoes or LL shoes, §7 performs a parametric study aiming to find the percentage of wagons equipped by LL shoes that provided relatively high Longitudinal Compressive Forces (LCF). This unfavourable percentage is used for all the other results of this deliverable.
It is important to note that also for this deliverable the most relevant parameters that affect the Longitudinal Train Dynamics (LTD), selected in D2.2, are considered. Once the 100 virtual train consists are generated, the technical parameters are set for each wagon and they are kept changing the number and position of active TU and/or the radio technology, i.e., the only difference between REF trains and DPS trains is the activation of the DPS, and the number of active TU.
Train consist of Reference train family is LWL; train consists of DPS family are LWL, LWLW and LWLWL. In the reference train family, there are two Drivers: one for each active TU. In the DPS train families there is only one Driver at the first TU[1].

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[1] Of course, during the experimental tests, there will be one Driver on each TU, instructed to intervene to keep the operation safe: see section 10. This topic is further addressed for simulations in D3.2.

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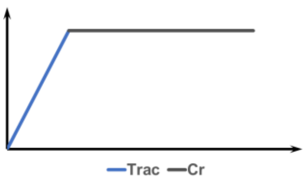
6. Description of Train Operations and Railway Track

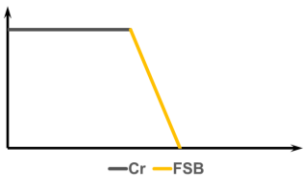
In reference system, there are two Drivers (one per TU), the Driver on the second TU supports driving the train by application of traction and ED force, but does not intervene on the brake pipe unless an emergency braking is commanded by the first Driver or an unexpected behaviour of the brake pipe pressure is recognized: in this circumstance an emergency braking is commanded by the second Driver, when the pressure in brake pipe is equal or lower to 3.5 bar at second TU.

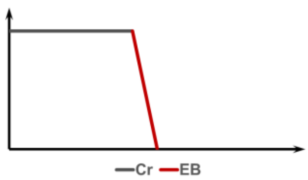
On the contrary, the DPS system fills or vents the brake pipe upon proper command transferred by the radio: the delay between the filling/venting of brake pipe at the leading TU and the filling/venting of brake pipe at guided TU, for LTE radio technology, is considered as a Gaussian random variable following what prescribed in D2.1. For each virtual train, this delay is randomly changed, and it is different among the two guided TU (if any) on each train. It is worthwhile to mention that when the system will be commercialized it is reasonable to expect a lower mean value for this delay, as assumed in D3.1.

DPS system vents the brake pipe also when a pressure drop of 0.2 bar is detected on the guided TU and the radio link is "down"[2]. Venting of brake pipe can be through a stepwise reduction of pressure in brake pipe (with target pressures at 4.5 bar, 4 bar and 3.5 bar) or directly by a full-service braking with target pressure 3.5 bar. Comparison among these two behaviours of DPS is addressed in §0.

10 (ten) scenarios are considered relevant for LTD: each one is designated by a number and other three digits (not specified here for sake of simplicity):

- 1xxx Train acceleration and then coasting (cruising): 

- 2xxx Full-service braking from coasting (cruising): 

- 3xxx Emergency braking from coasting (cruising): 

[2] Pictogram is 

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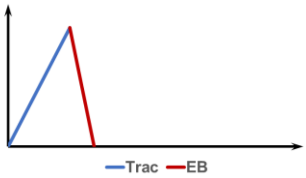
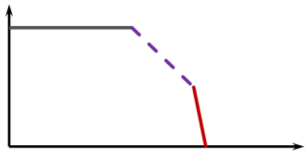
- 4xxx Train acceleration followed by an emergency braking: 

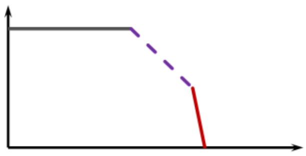
Above scenarios refer to DPS in nominal conditions, i.e. there is radio communication between the TUs and the DPS is working under favourable conditions. These conditions refer to pictogram:

Following scenarios refer to degraded conditions, i.e., the radio communication link is down. Train operations 5xxx and 6xxx refer to situations in which the radio link is lost *before* a new command is issued by the leading TU and which is corresponding to the following pictogram:

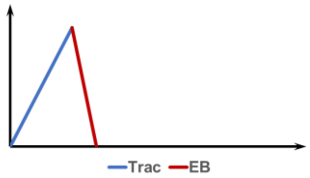
- 5xxx Train is accelerating, the radio link is down (DPS on guided TU reacts after "time of radio communication loss"), then the leading TU issues a braking.
- 6xxx train is braking (ED is activated), the radio link is down (DPS on guided TU reacts after "time of radio communication loss"), then the leading TU issues a "stronger" braking to stop the train.

  This scenario is meaningful on a downhill, mainly: 

Scenarios 7xxx, 8xxx and 9xxx refer to situations in which the radio link is lost *when* (i.e. in the same moment) a new command is issued by the leading TU and is linked to pictogram:

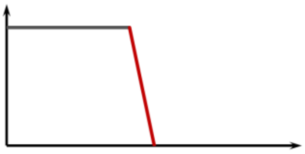
- 7xxx and 8xxx train is braking (ED is activated), then the leading TU issues a "stronger" braking (full-service braking for 7xxx and emergency braking for 8xxx) to stop the train and the radio link is down: DPS on guided TU reacts when it detects a pressure drop of 0.2 bar in brake pipe. These scenarios are meaningful on a downhill, mainly: 

- 9xxx train is accelerating, then the leading TU issues an emergency to stop the train and the radio link is down: DPS on guided TU reacts when it detects a pressure drop of 0.2 bar in brake pipe.



Last scenario refers to a condition in which an emergency braking is commanded by the guided TU, for any reason (e.g. fire on board or Driver error during the tests) in combination with communication loss.

- 10xxx train is running at a certain speed and an emergency braking is commanded by the guided

TU: 

For train consist LWLWL, condition in which the two TU behaves differently are analysed, too.
Not all scenarios are investigated with the same deepness in this deliverable, since the attention is focused on the scenarios that lead to highest LCF forces, dangerous for train derailment (according to UIC Leaflet 421).
This deliverable also analyses the stopping distance in §11.2 considering high train speeds in range 80-120 km/h to show the effect of the different two strategies to vent the brake pipe: stepwise or full brake application. Anyway, the stopping distance of DPS trains is always better than that of reference trains, as already proved during FP7 MARATHON Project, since venting the brake pipe in multiple points speeds up the brake application and reduces the stopping distance.
Furthermore, it is necessary to specify that, among all possible (theoretically infinite) working conditions, those chosen in this deliverable always consider the maximum braking force applied by all wagons or the maximum traction forces of all TUs (except the case LWLWL, specifically discussed later). Possible not nominal behaviours of the braking forces are considered by means of the technical parameters coming from D2.2, as done in D3.1.
As already shown in D3.1, if the traction forces are lower than the maximum values, the LTD is less enhanced. The train acceleration energizes the train in terms of kinetic energy (train speed) and potential energy (draw gears elongation); during the following braking, the braking devices and the couplings dissipate/transform such energy. If the initial potential energy (but not the train speed) is increased by increasing the traction force, the dissipation of this energy requires a higher deformation of buffers and draw gears, and this results in (usually) higher longitudinal forces.
The condition of wagons not braking is not examined, since it is not relevant for the test as they will not be used.
A general script has been prepared for this deliverable where the train operations can be simulated by TrainDy with the possibility to change the parameters that affect the LTD. Furthermore, in §10 some train operations are simulated considering the need for a Driver intervention during the tests.

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The railway track between Kronach and Probstzella has been chosen by FR8RAIL II Partners for the experimental trials. Section with highest track gradients is reported in Fig. 1.
Train operations of type 5xxx and 9xxx are more relevant (to emphasize the LTD) for the sections around point "UD", whereas 6xxx is more relevant for sections around point "DF".
Simulations on uphill/downhill railway track are reported in §9, where the train operations are simulated considering different characteristic positions along the railway track, around the points with higher slope variations, to emphasize the effects on longitudinal train dynamics.

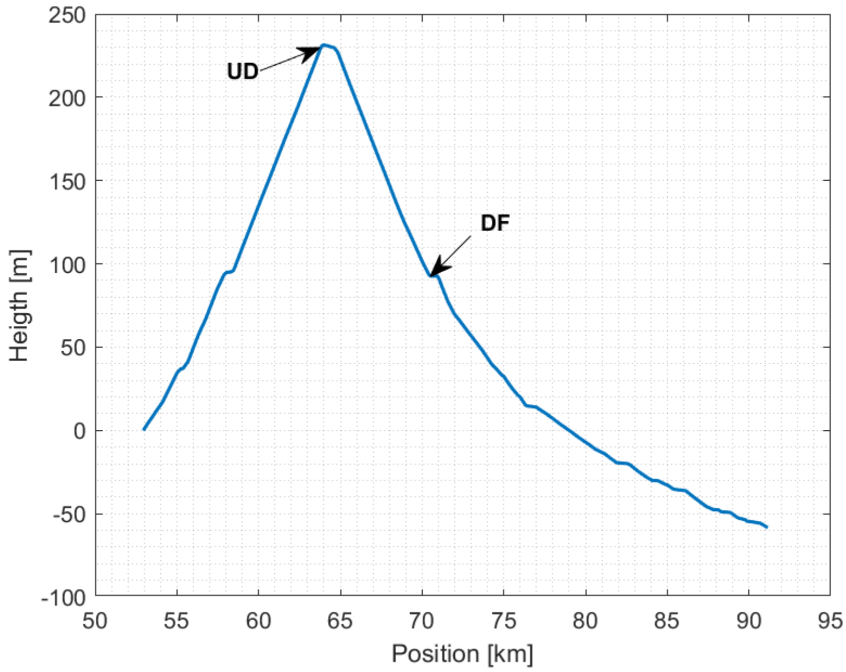

Fig. 1 Track with indication of the points UD and DF

7. Effect of wagons with LL shoes on LTD

The wagons of the trains that run on the railway track between Kronach and Probstzella are equipped by cast iron shoes. Since there is a transition from this type of shoe to LL shoe, a parametric study is performed considering a variation of wagons equipped by LL shoe from 0% (i.e., all wagons are equipped by cast iron shoe) to 100 % (i.e., all wagons are equipped by LL shoe). The chosen train operation belongs to 4xxx:

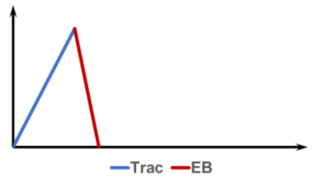

Fig. 2 reports a comparison of 10 m LCF (negative values) for reference system (a):

;

and for DPS system (b):

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among the possible DPS train consists, the LWLW is here selected since it shows a higher variation of Longitudinal Forces with respect to the other train consists (LWL and LWLWL). Each dot refers to a virtual train and represents the maximum (in absolute sense) 10 m LCF of that train.

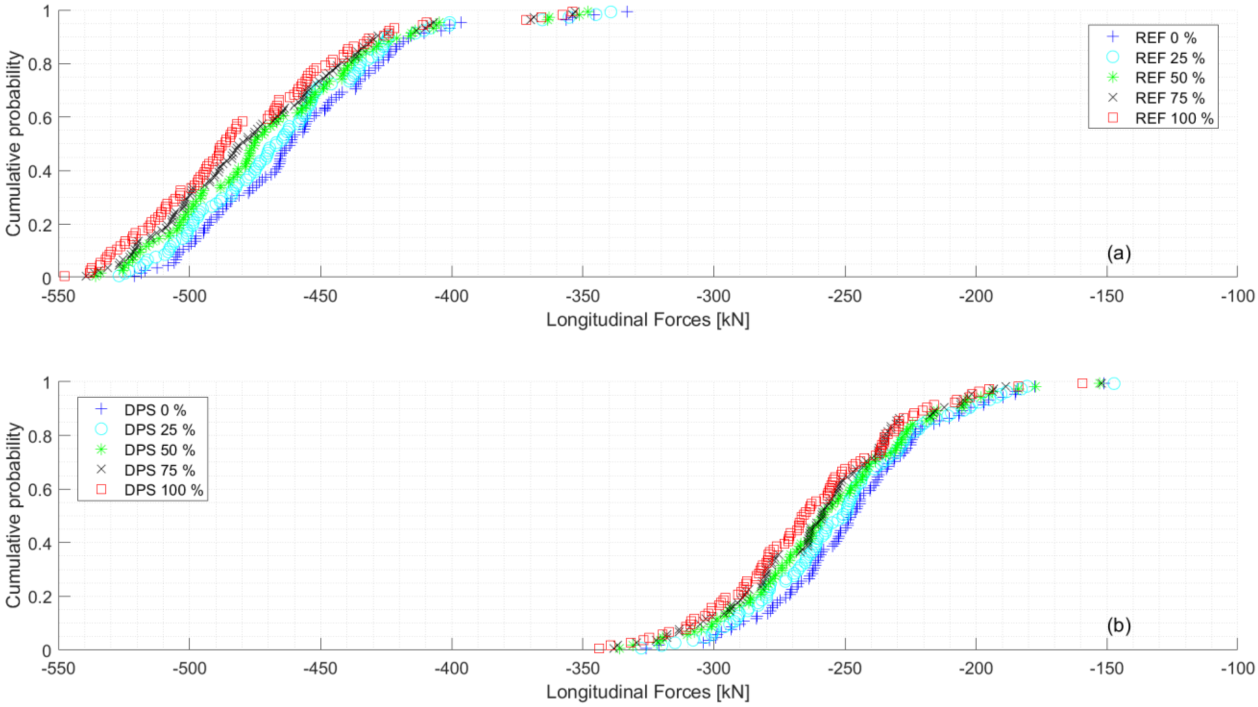

Fig. 2 Effect of percentage of wagons with LL shoe on LTD: (a) REF trains, (b) DPS trains.

Results of previous figure allow the following statements:

- DPS system behaves better than the reference system.
- When the wagons are all equipped by LL shoe, the LCF are higher both for reference and DPS system: see the red squares. Following simulations of this deliverable refer to this condition, i.e., all wagons are equipped with LL shoes: this is conservative with respect to the actual train tested by FR8RAIL II. This result is reasonable since LL blocks seem to provide slightly higher friction values in the lower speed range and the brake forces are increasing correspondingly. This is because the brake design of the wagons (originally developed for cast iron) is not changed. Only the blocks are replaced.

8. LTD on a planar track

A first set of simulations is executed on a planar straight track to reduce the order of complexity of the LTD problem; in this first round, the reference system is compared against the DPS system for the same train operation. As far as the relative approach is concerned (and the *TrainDy* simulations will show), the general advantage of a system of trains respect to another does not depend on the track gradient. Of course, the LTD highly depends on the track gradient but *less* the comparison between a reference and a new system (in this case, the DPS system), in general.

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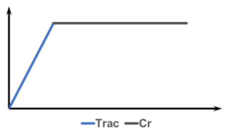
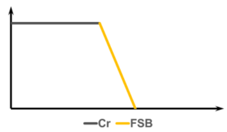
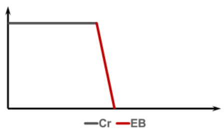
8.1. Train operations 1xxx, 2xxx and 3xxx (nominal)

These train operations are less dangerous for safety, with respect to the other train operations reported in this section. The pictograms of these train operations are:

	Train operation reported in Fig. 3 (a)		Train operation reported in Fig. 3 (b)		Train operation reported in Fig. 3 (c)

DPS is in nominal mode:  .

For DPS  only the 67% of maximum power is applied to provide the system with approximately the same amount of energy of the other train consists (with only two TU).

Fig. 3 reports, for each train family, the statistics given by the sum of the average (μ) longitudinal force plus or minus three times standard deviation (σ): $\mu \pm 3\sigma$, as it is done for a Gaussian distribution to cover the around the 99.7% of cases. For each train, the maximum (in absolute sense) 10m LCF and 2m LTF are determined. From all the maximum values of 10m LCF the average μ_C and the standard deviation σ_C are computed: according to TrainDy sign conventions μ_C is negative. Analogously, for 2m LTF the average μ_T and the standard deviation σ_T are computed: according to TrainDy sign convention μ_T is positive. The left ends of the horizontal bars correspond to the quantity $\mu_C - 3\sigma_C$ and the right ends to $\mu_T + 3\sigma_T$: these values are the only that matter in this graph: the maximum compression force is visualized in blue, the maximum tensile force range in red.

In this way, the results are more representative of the longitudinal forces variability and less dependent by the generated virtual trains. Of course, for LCF, the minus sign is used and for LTF the plus sign is used.

The results showed by Fig. 3 allows the following statements:

- LTF are close to the static values depending on the TU traction effort.
- LTF are excited by the acceleration (1xxx) and train-consist LWLW: see Fig. 3 (a).
- The longitudinal forces for a full-service braking and an emergency braking are comparable: see Fig. 3 (b) and (c). For this reason, next simulation scenarios in degraded mode will consider just the emergency braking and not the full-service braking.

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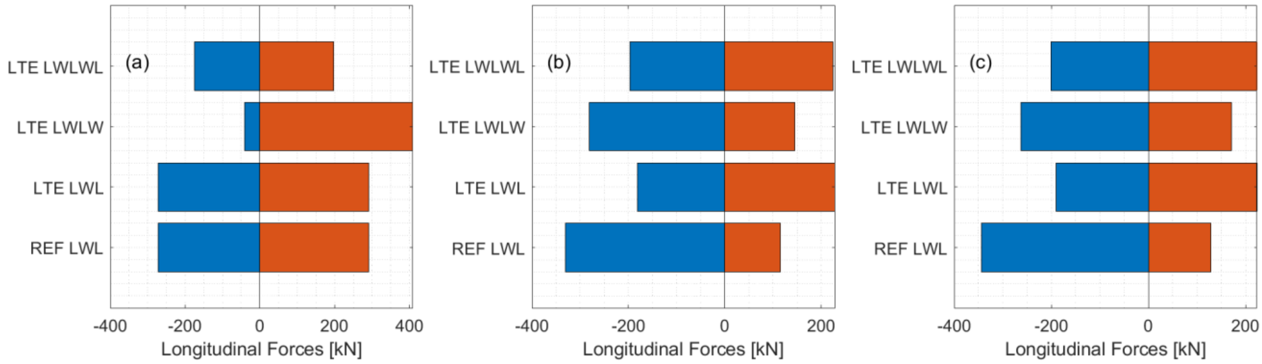

Fig. 3 (a) is 1xxx: only traction; (b) is 2xxx: full-service braking and (c) is 3xxx: emergency braking.

As the results of the following section will show, the above Longitudinal Forces are of no concern.

8.2. Train Operation 4xxx

The pictograms used for this type of operation are:

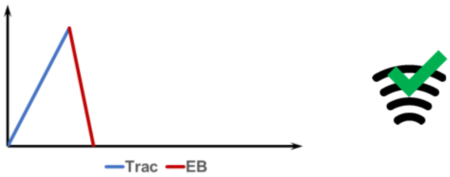

Fig. 4 reports the traction force at the TU, along with the train speed, on the left and the pressures in brake pipe and in the brake cylinders for the TU on the right, for reference and DPS systems[3]. For the reference system, the second Driver "reacts" to an emergency braking command communicated by the Driver on first TU with a certain delay. This delay is a random variable and, in agreement with FR8RAIL II Partners it has modelled as a Gaussian distribution with mean value 5 s and coefficient of variation equal to 0.1: this is the delay between the first venting of brake pipe at the first TU and the first venting of brake pipe at the second TU.

For the DPS system, the guided TUs replicate the command of the leading TU with a random delay. Note that to provide the same amount of energy to the system during the acceleration, the power of the TU is reduced to 67% of the maximum value, for train consist LWLWL 

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[3] Plots about mechanical and pneumatic parameters always refer to the first virtual train (among the 100 generated), by convention.

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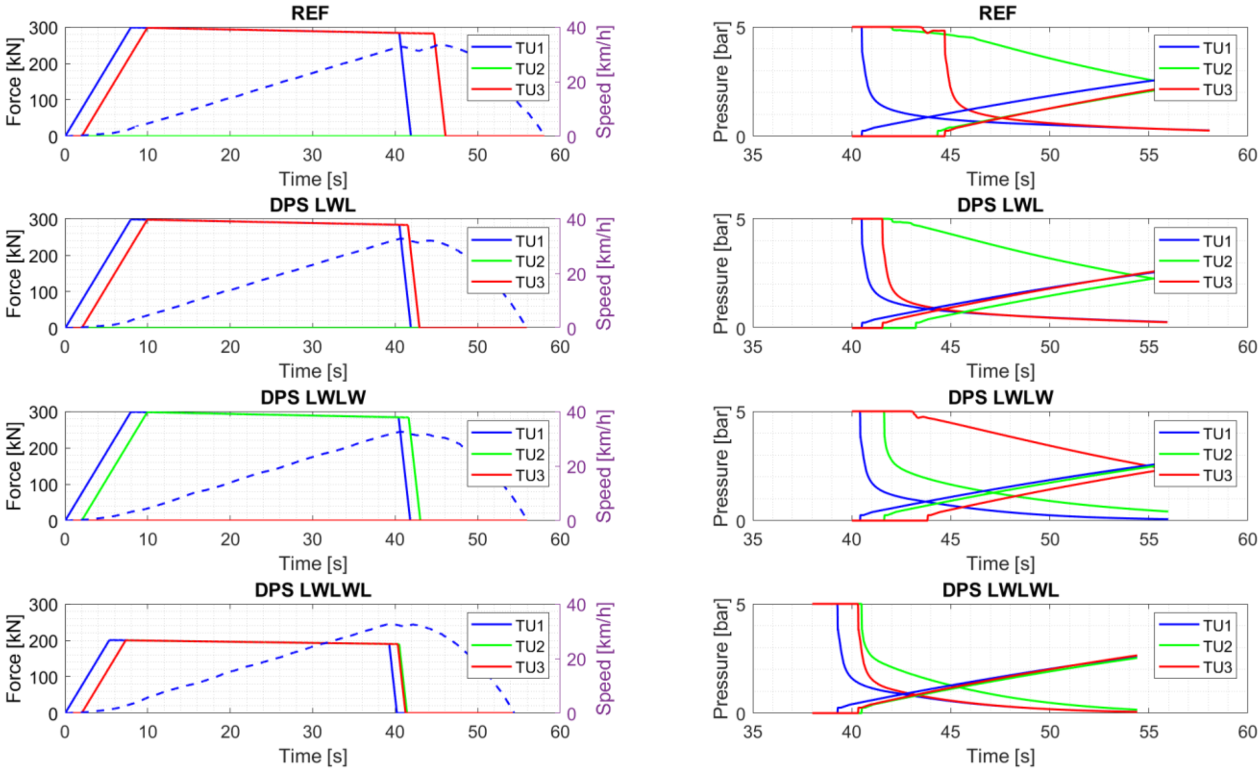

Fig. 4 Mechanical and pneumatic parameters for 4xxx.

Fig. 5 reports a comparison of LF between reference and DPS system (for different train consists): as before, each "dot" refers to a virtual train. This figure shows that the reference system is worse than the DPS system for LCF and it is like DPS system for LTF except for LWLW: for this train operation LTF of DPS system are bigger than those of REF system: anyway, the forces are below 550 kN, which is a value that can bring to train disruption in a due time, because of fatigue phenomena.

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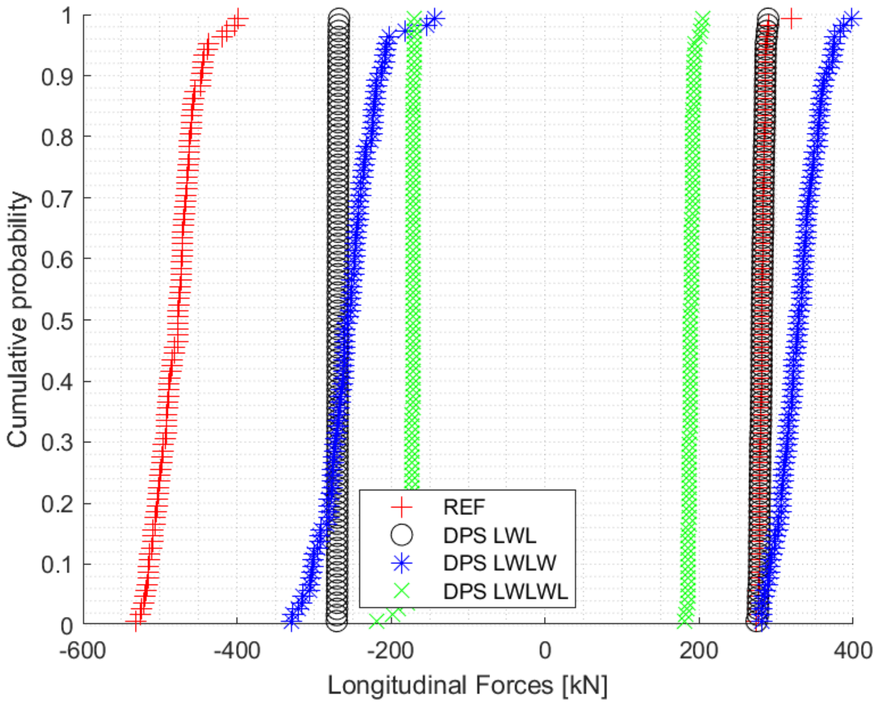


Fig. 5 4xxx, cumulative probability of Longitudinal Forces.

Finally, Fig. 6 reports a comparison among the reference system and the three different DPS systems: each point represents a virtual train. The point's abscissa is the 10 m LCF of the reference system, the point's ordinate is the 10 m LCF of the DPS system: both values are expressed in kN. If the point lies below the first bisectrix it means that the DPS system is better (i.e. safer) than the reference system.

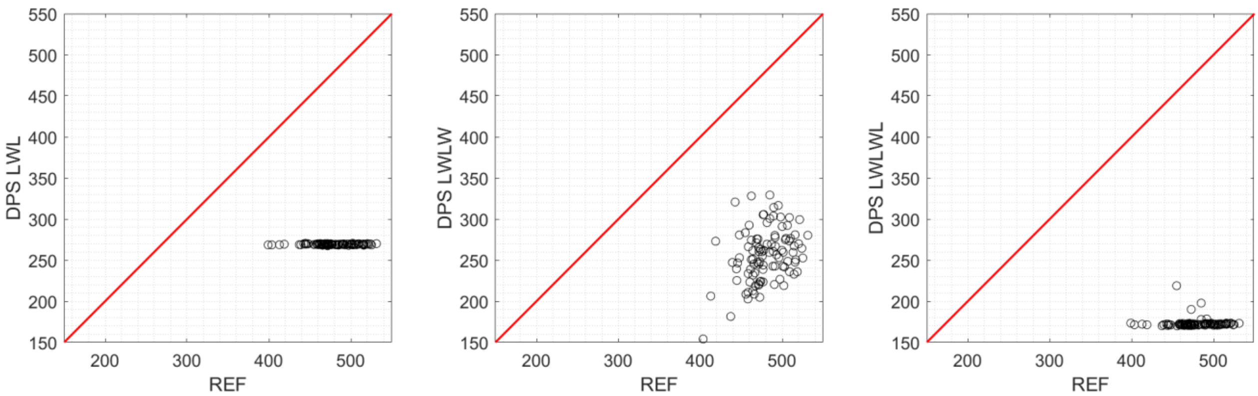
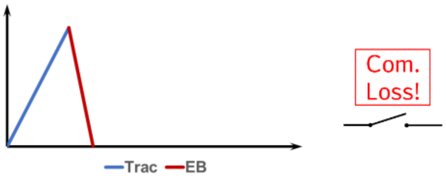


Fig. 6 4xxx, one to one comparison of LCF [kN].

8.3. Train operation 5xxx

The pictograms used for this type of operation are:



In this train operation, the communication loss occurs during the acceleration *before* the Driver, on the leading TU, performs the emergency braking. This scenario has been found particularly dangerous during the experimental tests of May 2019, made by FFL4E Partners. During this scenario, power is removed at the guided TU with a gradient of approximately 60 kN/s[4] when the system declares a communication loss, i.e., when there is no radio link for more than a designated time interval. This time interval for radio communication loss is set to 2.5 s, currently: §11.1 reports a parametric study on the effect of this time interval variation.
To proper compare the behaviour of reference system and DPS system, it is necessary to replicate the same manoeuvre for the reference system, i.e. to assume that a communication loss occurs also for reference trains. For the train-consist indicated as LWLWL, it is assumed that the communication loss occurs on all TUs: this occurrence is more dangerous than the communication loss just on one TU.

[4] The TU removes the traction force within 5s, but the current official UIC TrainDy version cannot manage variable gradients. However, most simulations reported here in this document use full traction. Thus, the fixed gradient complies well with the simulation cases that are considered in the following and these cases are the basis for the test specification.

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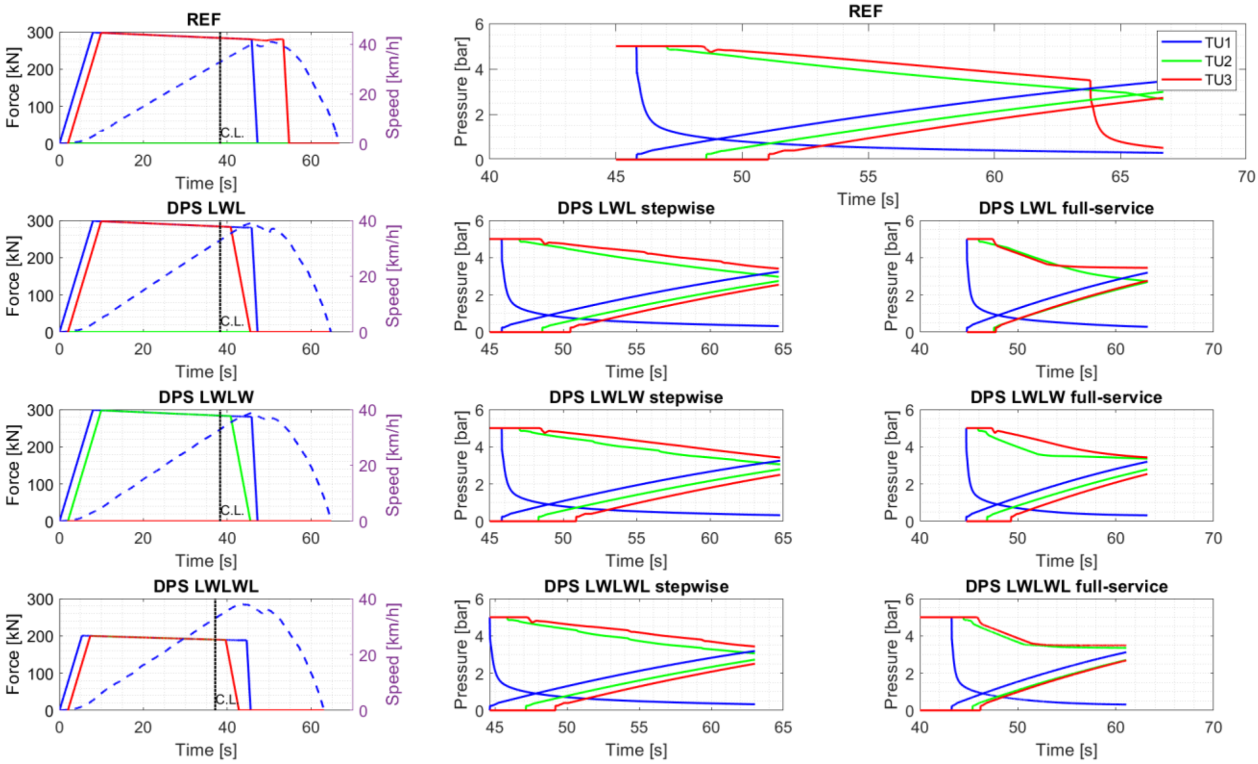

Fig. 7 Mechanical and pneumatic parameters for 5xxx (traction forces and brake pipe pressure). For readability sake, legend is reported just one time, but it applies to all sub-plots.

Fig. 7 reports the traction force at the TU, along with the train speed, on the left and the pressures in brake pipe and in the brake cylinders for the TU on the right, for reference and DPS systems. A vertical line to indicate the moment of initial communication loss (C.L.) is also displayed. For reference system, the traction force is reduced when there is a pressure drop of at least 0.4 bar (miming an interlock) and the emergency braking is commanded if the pressure in brake pipe at the second TU reaches 3.5 bar. The DPS system reduces the power, when the time interval for radio communication loss is overcome[5]; when the emergency braking is commanded by the leading TU, the DPS system has two operational ways: a) stepwise reduction of pressure; b) full-service braking.

As before, Fig. 8 reports a comparison among the reference system and the three different DPS systems, first row refers to a comparison among the REF system and the DPS system with stepwise reduction of pressure (when a first pressure drop of 0.2 bar is detected at guided TU); the second row reports the comparison among the two possible operative ways of DPS system: stepwise reduction and full-service braking (when a first pressure drop of 0.2 bar is detected at guided TU). The first row shows that the DPS system is safer than the REF system. The second row shows that the benefits of full-service braking are minor: since the dots are close the bisectrix; for LWLW train consist, sometimes the stepwise reduction is better than the full-service braking and some others not; this topic is further addressed in §0. The number of dots that are above the bisectrix is a rough estimation of the probability that the DPS system (or a system on Y axis) is worse than the REF

[5] As said before, this time is set to 2.5 s, currently.

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system (or a system on X axis). Of course, the probability that the system on the X axis is worse than the system of Y axis is the complement to 100% and it is reported in Fig. 8.

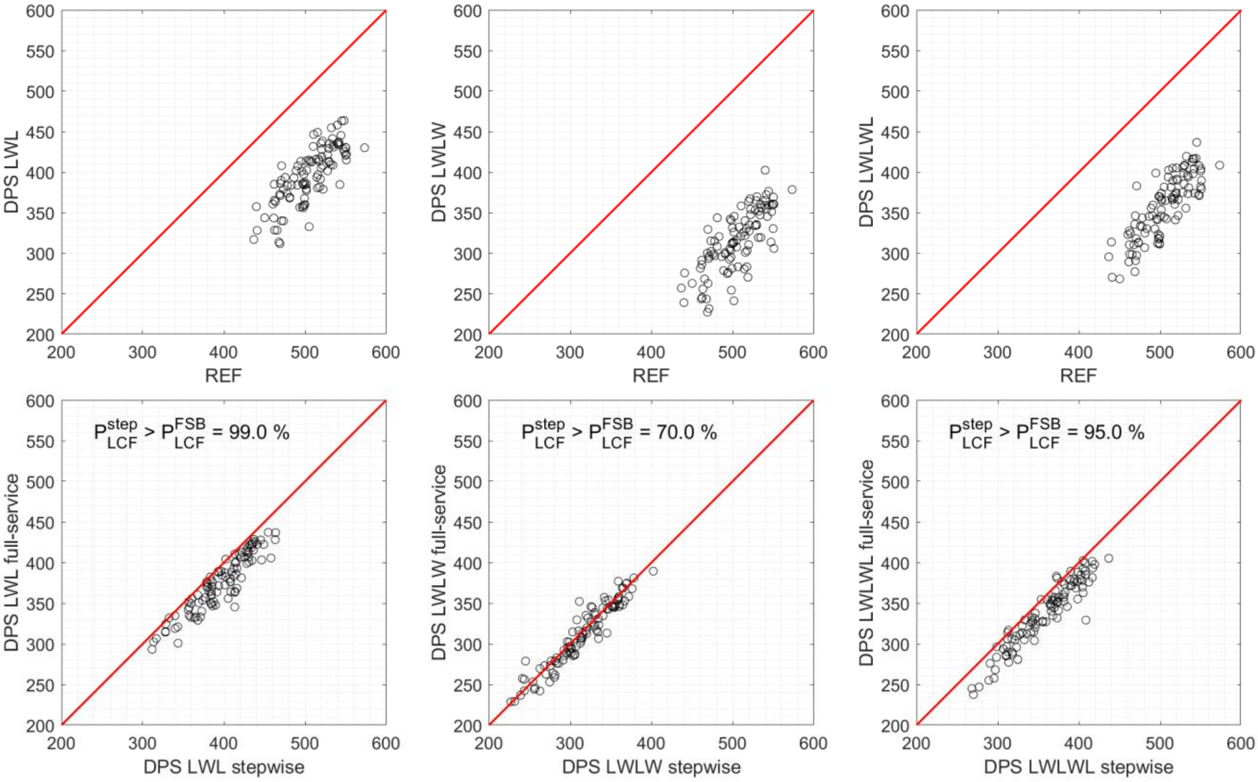

Fig. 8 5xxx, one to one comparison of LCF [kN]: first row refers to a comparison against REF system, second row refers to the comparison among stepwise reduction and full-service braking application.

Fig. 8 refers to a condition in which the Driver applies the emergency braking *after* the traction is removed at guided TU; Fig. 9 compares the LCF when the Driver applies the emergency braking *just after* the traction removal starts at guided TU against the LCF when the Driver applies the emergency braking *after* the traction removal (i.e., when there is no traction at guided TU). In both cases, the pressure at the guided TU is reduced *stepwise*. This figure shows that, applying the emergency braking contemporary to traction removal at guided TU is usually worse than the condition in which the EB is commanded as soon as traction is removed at guided TU. Therefore, the condition reported in Fig. 8 is the most severe in terms of LCF. It is worthwhile to mention that during the tests of May 2019 by FFL4E Partners, the most severe condition has been tested.

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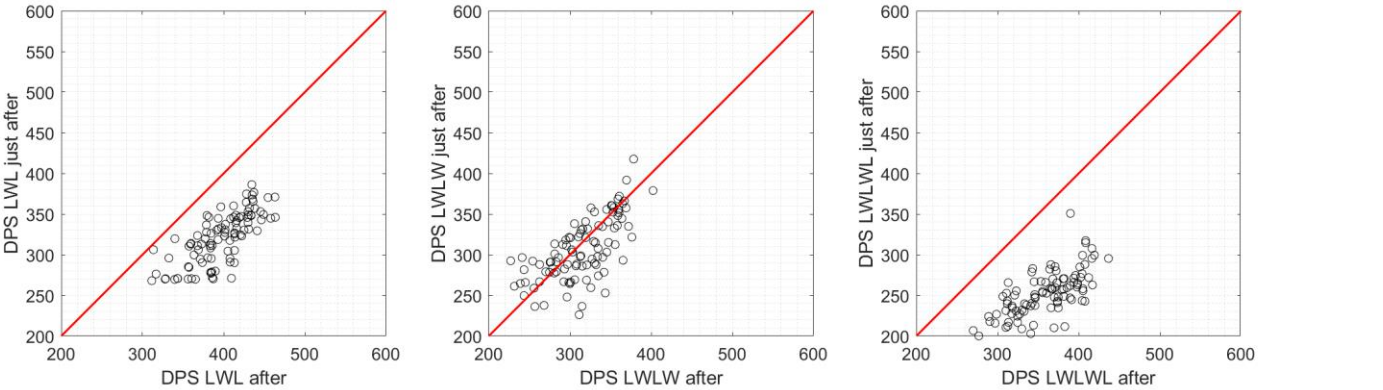
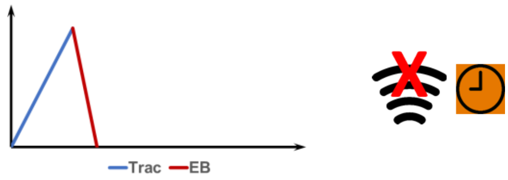


Fig. 9 5xx1, comparison among LCF [kN] when Driver applies EB after the traction removal or just after the traction removal starts.

8.4. Train operation 9xxx

The pictograms used for this type of operation are:



In this train operation, the communication loss occurs *when* (i.e., at the same time) the Driver on the leading TU performs the emergency braking. During this scenario, traction force is removed at the guided TU with a gradient of 200 kN/s when the system detects a pressure drop of 0.2 bar. This scenario is like that tested in May 2019 by FFL4E when the traction force was removed considering the time and not the pressure drop in brake pipe.

To proper compare the behaviour of reference system and DPS system, it is necessary to replicate the same manoeuvre for the reference system. As for scenario 5xxx, for the train-consist indicated as LWLWL, it is assumed that the communication loss occurs on all TUs: this occurrence is more dangerous than the communication loss just on one TU.

Fig. 10 is like Fig. 7 and it is not described again, here. This time, the Driver commands the EB **and** the communication loss occurs at the same time; when the pressure drop of 0.2 bar is detected, the guided TU removes the traction with a gradient of 200 kN/s and reduces the pressure stepwise or by a full-service braking. In REF system, the traction is removed from the guided TU when the pressure drops to 4.5 bar (miming an interlock).

As before, Fig. 11 reports a comparison among the reference system and the three different DPS train consists, first row refers to a comparison among the REF system and the DPS system with stepwise reduction of pressure; the second row reports the comparison among the two possible operative ways of DPS system: stepwise reduction and full-service braking (when a first pressure drop of 0.2 bar is detected at guided TU). The first row shows that the DPS system is safer than the REF system. The second row shows that the benefits of full-service braking are minor: since the dots are close the bisectrix; for LWLW train consist, sometimes the stepwise reduction is better than the full-service braking and some others not; this topic is further addressed in §0.

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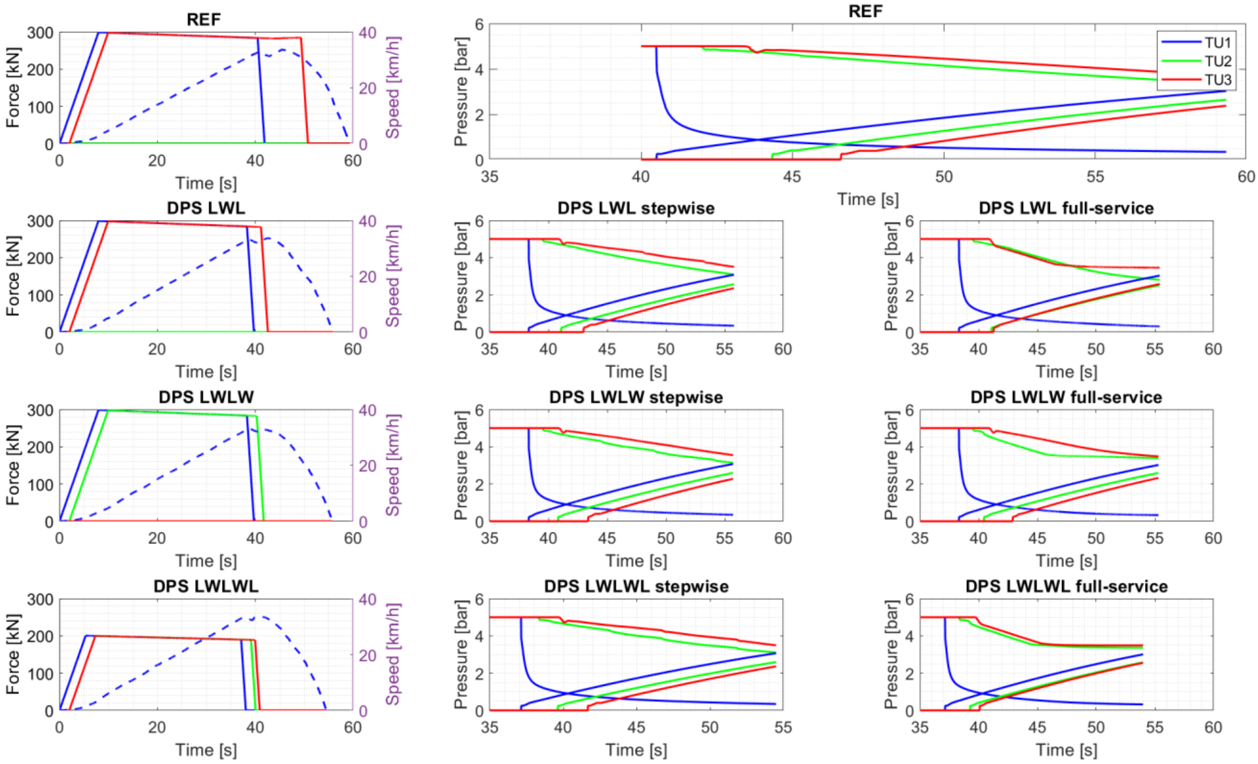

Fig. 10 Mechanical and pneumatic parameters for 9xxx (traction forces and brake pipe pressure). For readability sake, legend is reported just one time, but it applies to all sub-plots.

The results of this section demonstrate again that the DPS system is safer than the reference system, also in this degraded mode. This safety is roughly the same if the pressure in brake pipe is reduced stepwise or by a full-service braking: second behaviour is slightly better for safety and for stopping distance. This topic is further addressed in §0.

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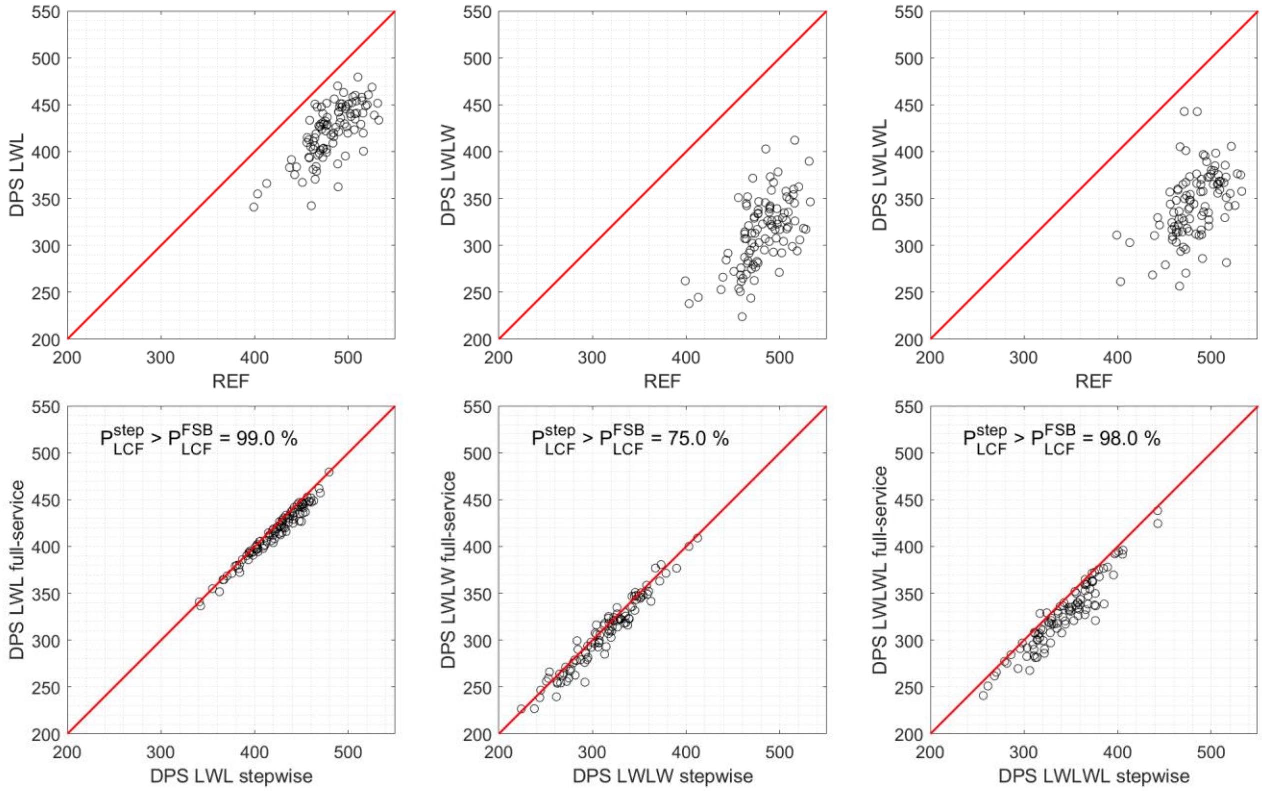

Fig. 11 9xxx, one to one comparison of LCF: first row refers to a comparison against REF system, second row refers to the comparison among stepwise reduction and full-service braking application.

8.5. Train Operation 10xxx

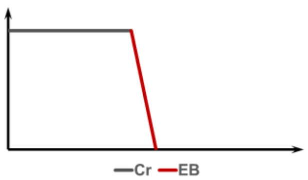

Fig. 12 (a)

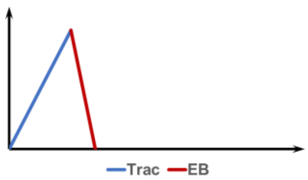

Fig. 12 (b)

This scenario only refers to the demonstrator as the functional safety cannot be guaranteed at this stage of the design process. Two conditions are considered: the emergency braking is commanded by a guided TU during cruising (a) or during an acceleration (b). Second condition is prone to train disruption: because of relative speeds of the two segments of train, i.e., at location of high LTF, the wagons relative speed causes a separation of the two coupled wagons.
This scenario has several different alternatives; results reported here refer to the occurrence of an emergency braking commanded by the second/guided TU and the loss of radio communication, therefore a degraded mode.
In the reference system, if the EB is commanded by the second TU during the cruise, the Driver on first TU vents the brake pipe when the pressure in BP is 3.5 bar (behaving similarly to what done in previous scenarios). If the EB is commanded during an acceleration, the traction interlock reduces the traction effort at the second TU and the Driver at the leading loco removes the traction when pressure is 4.5 bar and commands the emergency braking when the pressure is equal to 3.5 bar.

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In the DPS system, for train consists with just one guided TU like LWL 

or like LWLW 

, the Driver on the leading TU behaves as on reference train: traction is removed when pressure is 4.5 bar and emergency braking is commanded when the pressure in brake pipe is 3.5 bar. If the train consist has two guided TU, LWLWL 

, it is necessary to distinguish which TU starts the EB: it can be the 2nd or the 3rd; both cases are addressed here. For train consist LWLWL, the other TU that is not commanding the emergency brake and is assisted by the DPS functionality, behaves in the usual way when there is a radio communication loss: when it detects a pressure drop of 0.2 bar, the traction is removed and the pressure is reduced; only the stepwise reduction is reported here, since it was the "relatively" most dangerous, in terms of LCF.

Fig. 12 reports the same statistics of §8.1.

In this figure, (a) refers to the EB commanded from cruising or coasting conditions and (b) from full acceleration. For LWLWL train consists, the TU that activates the EB is reported, as well. The results of Fig. 12 allow the following considerations:

- Train scenario 10xxx is not relevant for LCF, i.e., for derailment risk.
- DPS system behaves always better or equal to REF system: they are the same for the train consists LWL, as expected. Anyway, it can be assumed that an emergency braking of one of the guided TU, in combination with a simultaneous radio link loss, is considered as a rare case.
- This scenario can bring to a train disruption, but this risk is lower (or equal) for DPS system, since with DPS the LTF are lower (or equal) to REF system.

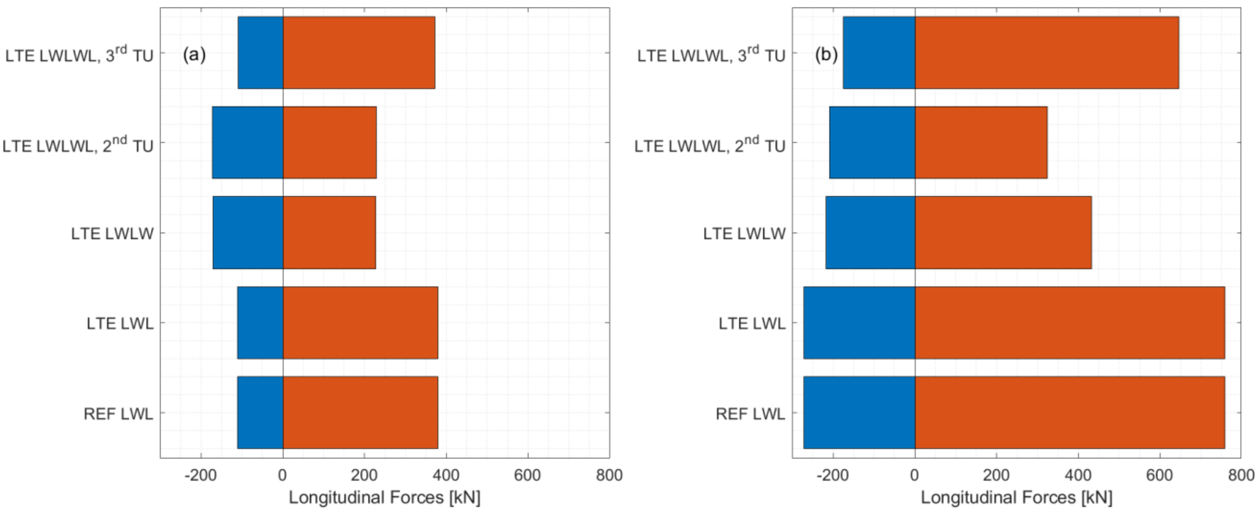

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Fig. 12 10xxx, (a) EB is commanded from cruising and (b) EB is commanded from full acceleration conditions. Negative values are LCF and positive values are LTF.

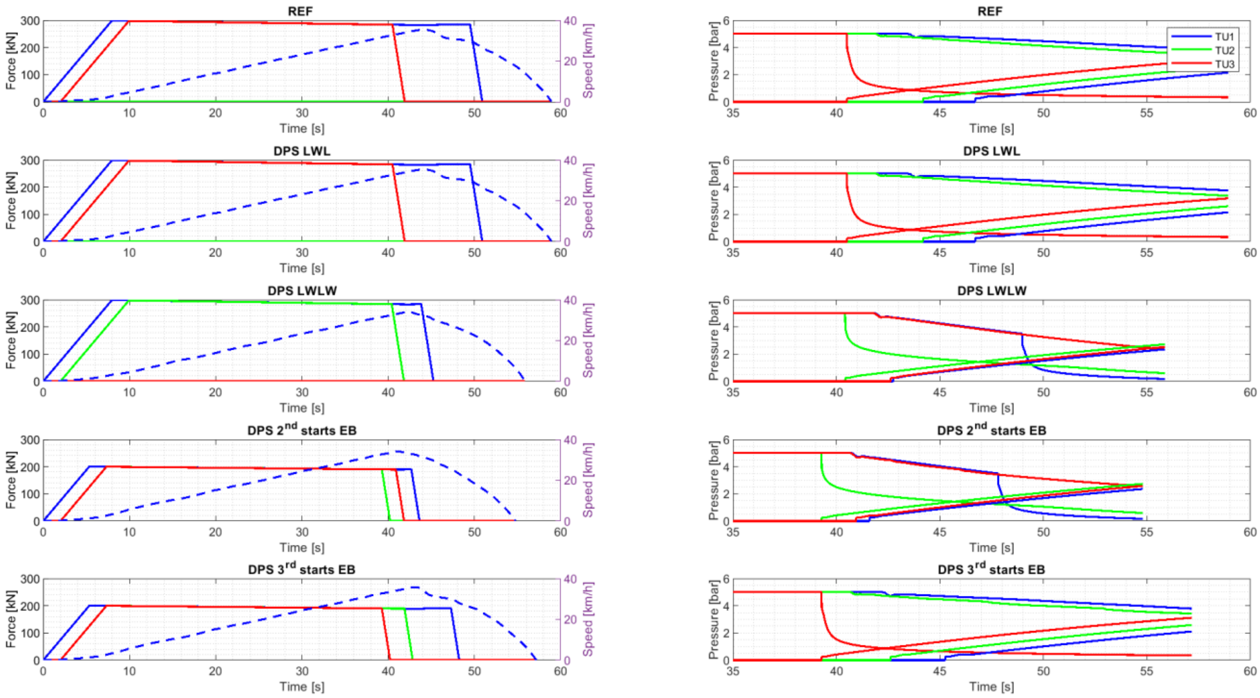

Fig. 13 reports the traction forces and the pressure in brake pipe and brake cylinders for train operations 10xxx: traction force is removed when the pressure in brake pipe is 4.5 bar and emergency braking is commanded by the Driver when the pressure is 3.5 bar.

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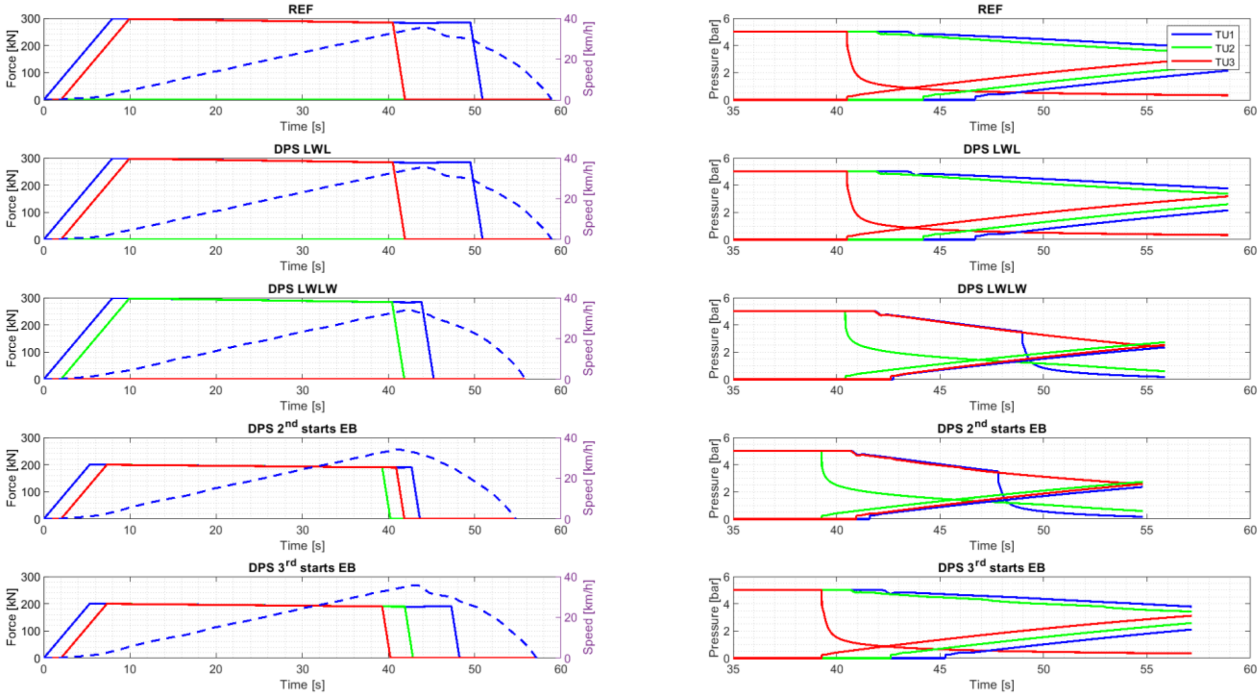


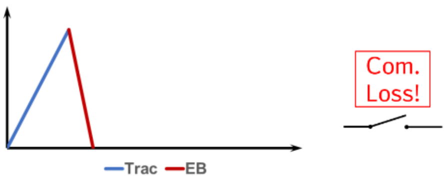
Fig. 13 Mechanical and pneumatic parameters for 10xxx (traction forces and brake pipe pressure). For readability sake, legend is reported just one time, but it applies to all sub-plots.

9. LTD on Up/Down-hill

In this section, the train operations 5xxx and 9xxx are repeated, moreover, also the 6xxx, 7xxx and 8xxx train operations are reported. 5xxx and 9xxx are repeated since these train operations proved to be the most dangerous on a planar track.
When the train is on a non-planar track, the LTD problem is more complex since the in-train forces depend on the position of the train on the track and not only on the train consist or the train operation. As anticipated in section 6, two points will be considered on the track: "UD" and "DF": the first is used for manoeuvres involving traction, the second for manoeuvres involving a braking plus and electro-dynamic braking. The likelihood of a traction application is bigger on an uphill and the likelihood of a braking (electrodynamic or electrodynamic + pneumatic) is bigger on downhill. For each train operation, five representative points are chosen in the nearby of UD and DF: distance among these points is equal to 740/5≅150 m.

9.1. Train operation 5xxx

The pictograms used for this type of operation are:



In this train operation, the communication loss occurs during the acceleration *before* the driver, on the leading TU, performs the emergency braking. Power is removed at the guided TU when the

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system declares a communication loss. This time interval for radio communication loss is set to 2.5 s, currently.

For this train operation, the five points are reported in Fig. 14. At these points, the leading TU reaches 30 km/h during the acceleration: this requires the computation of a suitable starting point for the train simulation. This problem has been solved by implementing an algorithm for the zero of a function: therefore, each point requires a different starting point and this point changes (a little) with the train consist, i.e., LWL, LWLW or LWLWL. At UD, the leading TU is at the top of the track; at UD+740, the leading TU is close to the (steep) down-hill: therefore, when emergency braking is applied at UD, the train first part is down-hill and second part is up-hill; at UD+740 all the train is down-hill, but the first part on a side with higher gradient.

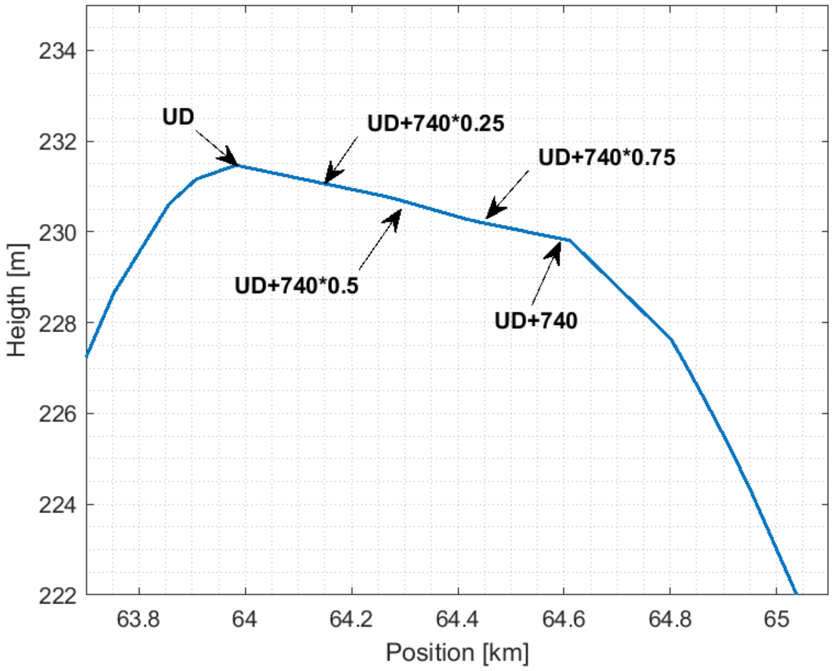

Fig. 14 Track with indication of the points used for 5xxx and 9xxx

Fig. 15 shows the comparison between REF and DSP systems for the five different positions above and for different train-consists. In this figure, DPS operates with a stepwise reduction of pressure in brake pipe. For each row, a text box reports the location of the leading TU at 30 km/h. A comparison of this figure against Fig. 8 allows the following statements:

- LCF depends on track gradient.
- The comparison between DPS and REF system does not depend on track gradient: DPS is better than REF system for 5xxx both on planar and on up/down-hill.

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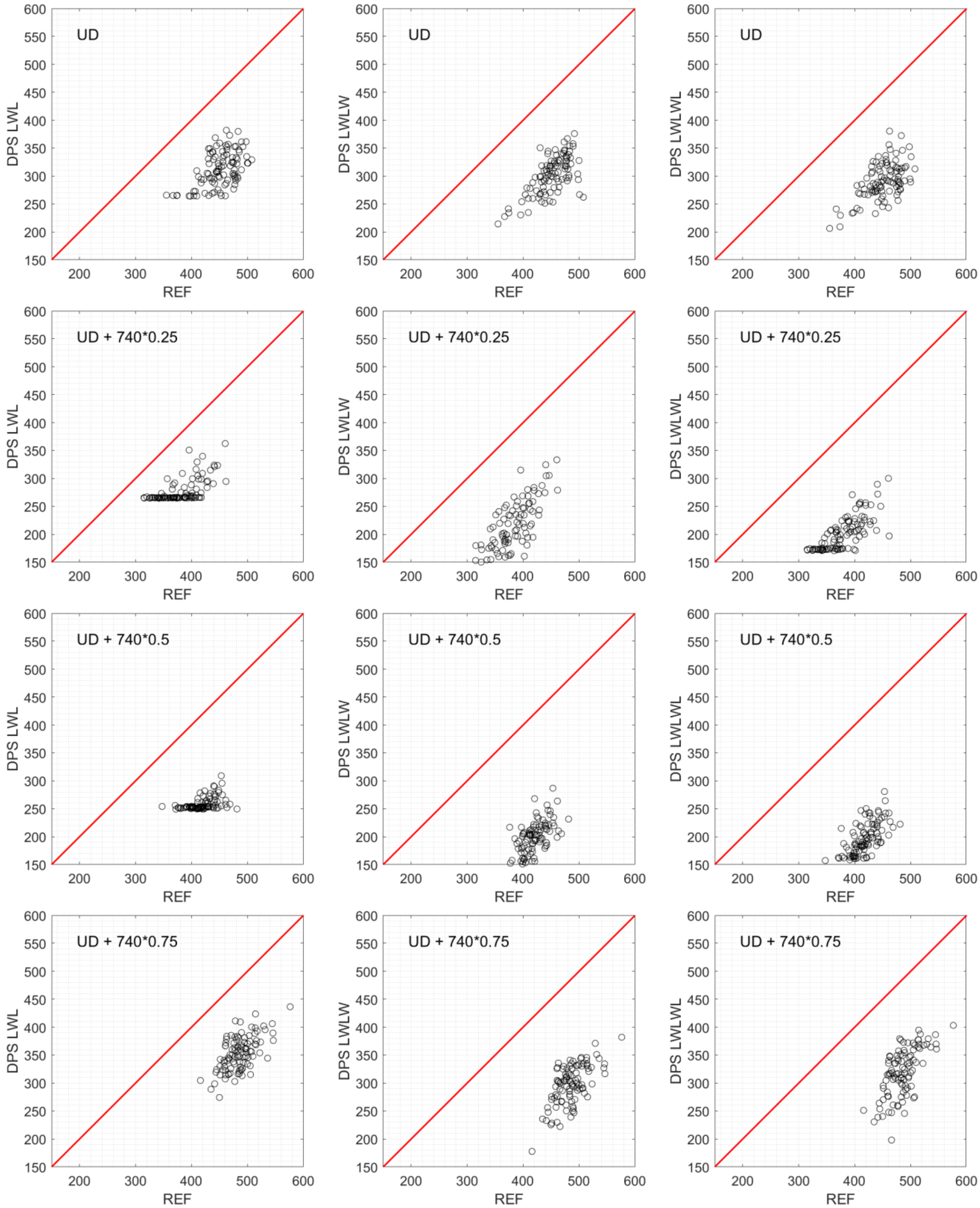

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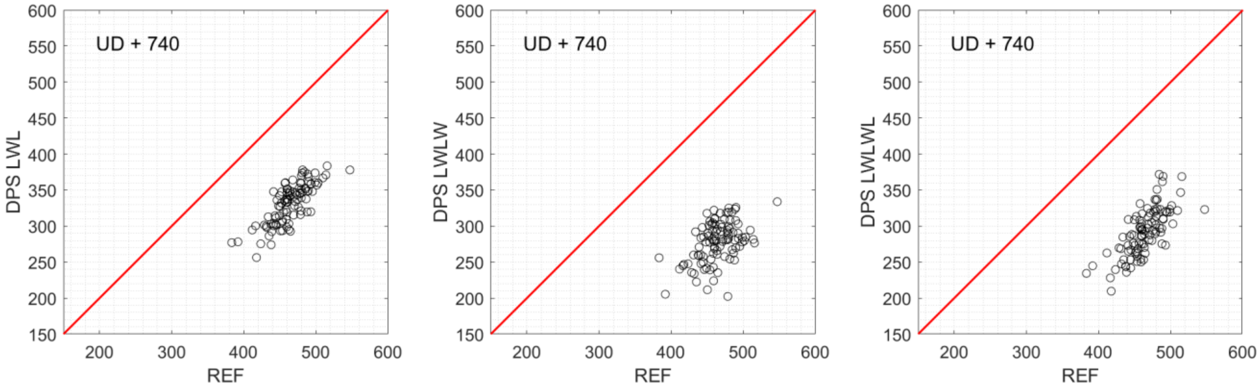
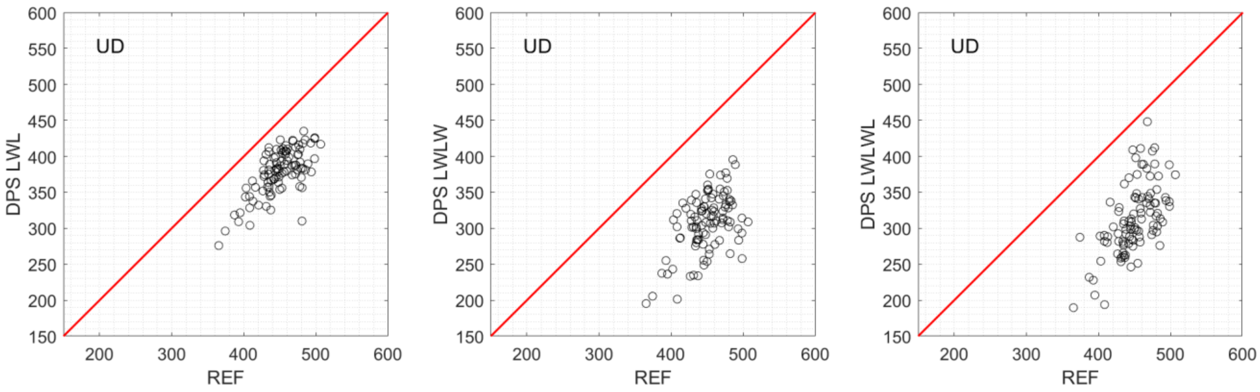


Fig. 15 Different applications of 5xxx, close to point UD.

9.2. Train operation 9xxx

For this train operation, the five points are the same of the previous sub-section.
Fig. 16 shows the comparison between REF and DSP systems as in Fig. 15. A comparison of this figure against Fig. 11 allows the following statements:

- LCF depends on track gradient.
- The comparison between DPS and REF system does not depend on track gradient: DPS is better than REF system for 9xxx both on planar and on up/down-hill. Anyway, there are some track positions and train-consists (LWL) for which the two system are closer: see the circle close to the red line.



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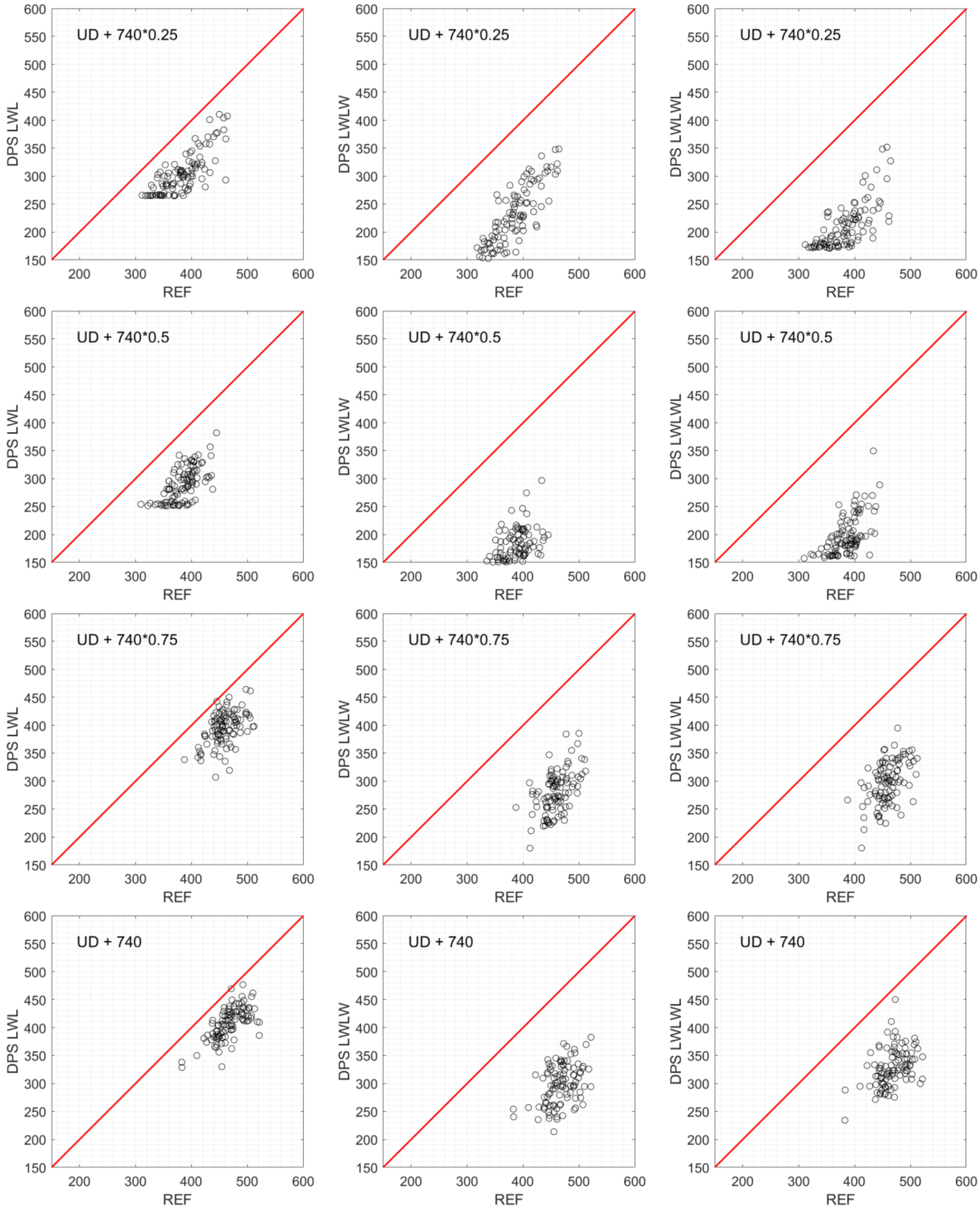

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Fig. 16 Different applications of 9xxx, close to point UD.

9.3. Train operation 6x0x

Train family 6xxx has two main variants: first variant assumes the initial application of just ED braking (6x0x) with its maximum force (fully applied), discussed in this section, and second variant assumes the application of ED braking + first application step of pneumatic brake (FAS: target pressure in brake pipe is 4.5 bar, sub-family: 6x1x), discussed in the next subsection. For this train operation, the radio link is lost before the Driver on the leading TU commands an EB:

On the leading TU, when EB is issued, the ED is reduced to the maximum pneumatic brake force of 73 kN in 30 s with respect to brake regime G.

For this train operation, the five points are reported in Fig. 17: these points are placed differently around DF (compared to the points around UD of Fig. 14) to simulate the LTD on down-hill and when one part of the train is down-hill and anther on a flat track. At these points, from the initial speed of 25 km/h, the leading TU reaches 30 km/h: this requires the computation of a suitable starting point for the train simulation, as before.

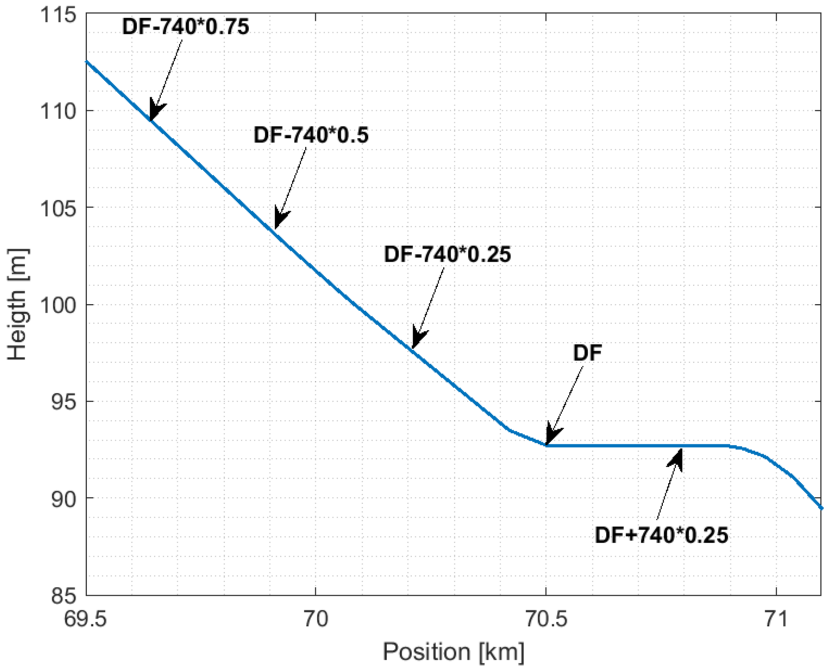

Fig. 17 Track with indication of the points used for 6x0x.

Fig. 18 shows the comparison between REF and DSP systems in terms of LCF for the five different positions above and for different train consists. In this figure, DPS operates with a stepwise reduction of pressure in brake pipe.

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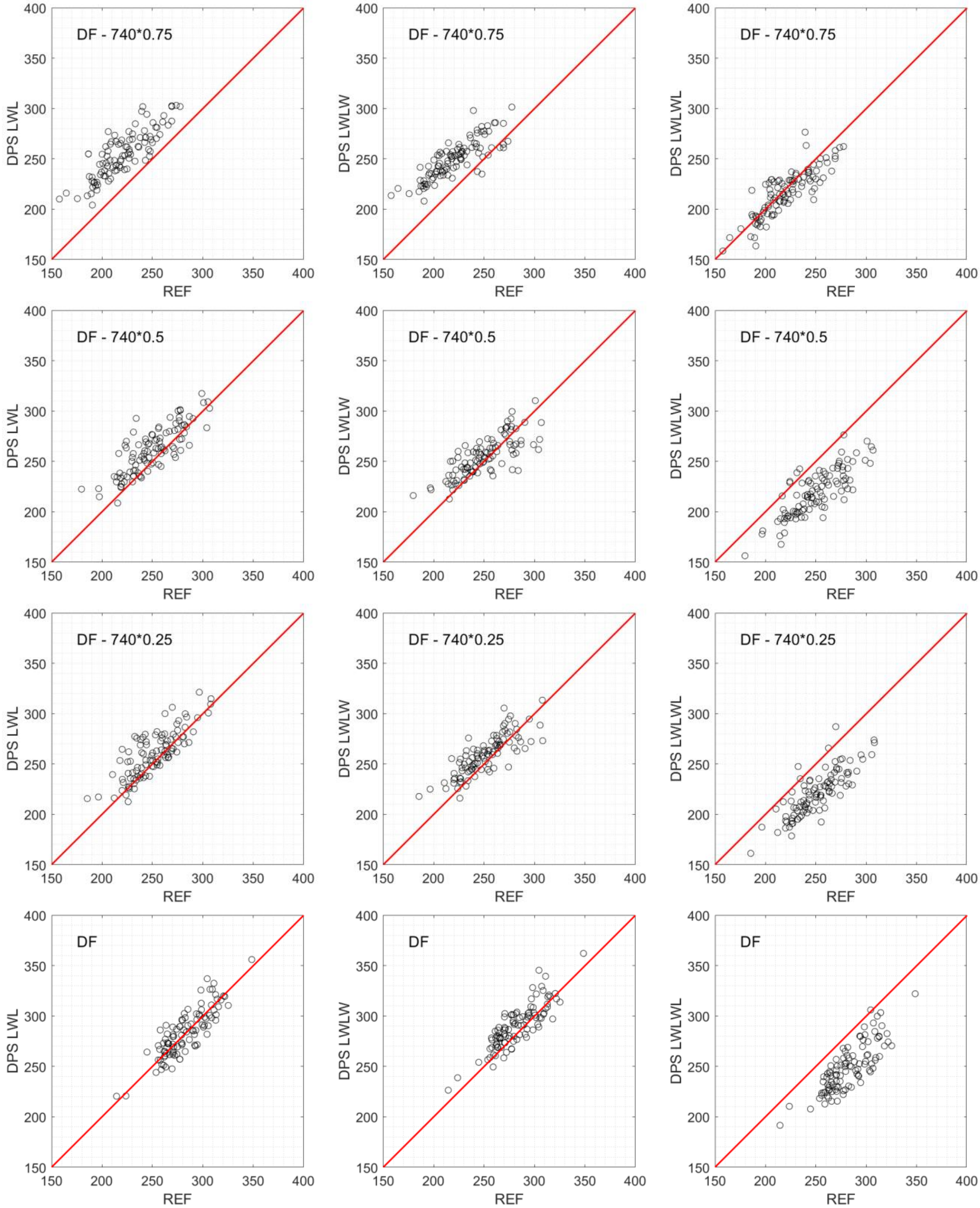

This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no. 826087 (M2O)

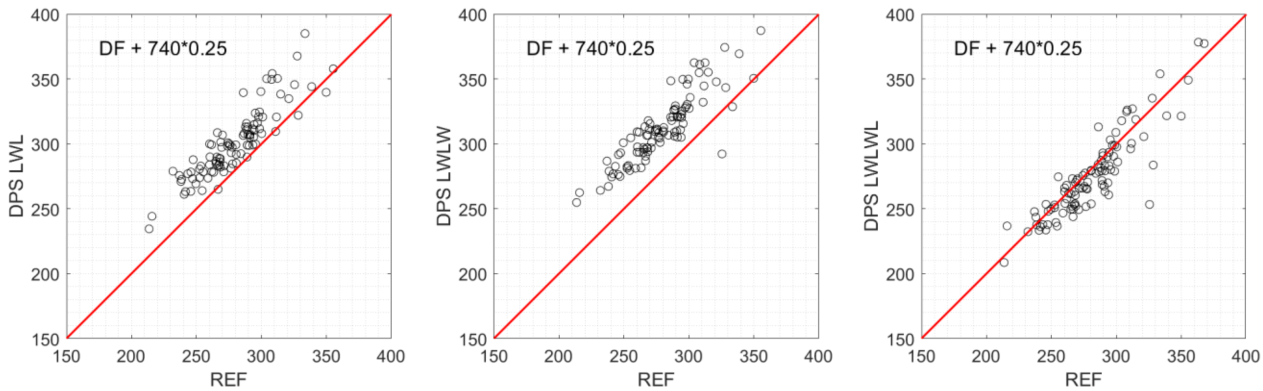

Fig. 18 Different applications of 6x0x, close to point DF.

Fig. 18 allows the following statements:

- LCF are lower than those of train operations 5xxx and 9xxx. They are of no concern since they are like those obtained in nominal mode of reference system (see Fig. 3); anyway, they do not exceed 400 kN which is considered a "safe" value for Longitudinal Compressive Forces according to UIC Leaflet 421 [2].
- LCF are bigger for DPS system than for REF system. The reason is the removal of Electrodynamic brake because of radio communication loss. See Fig. 19 for a comparison of in-train forces for REF and DPS system at location DF (similar behaviour for other locations): in-train forces start to differ among REF and DPS system when the ED brake of *guided* TU is removed. ED brake removal creates a compression wave (ED brake of the guided TU stretches a part of the train) that increase the level of in-train forces. The effect of time interval for communication loss is addressed again in subsection 11.1.
- For 

train consist the LCF are quite similar between REF and DPS system.

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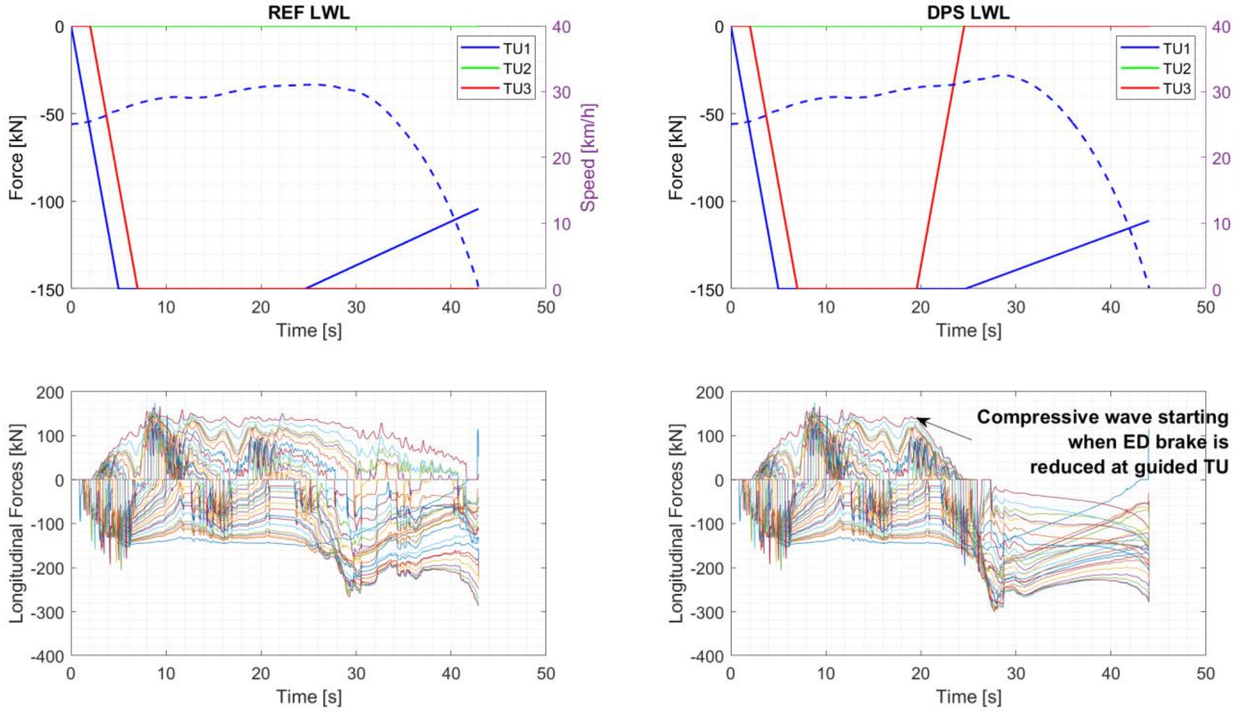

Fig. 19 In-train forces and mechanical parameters for REF and DPS LWL in train operation 6x0x at location DF.

9.4. Train operation 6x1x

This train operation is like that of previous subsection with the only difference that the initial status is fully applied ED braking + FAS (i.e., service braking with target pressure in brake pipe of 4.5 bar). As before, from this condition, a communication loss occurs:

After the ED brake is removed the leading TU applies an emergency braking. The starting speed for this train operation is 40 km/h and the initial position is determined so that the speed of 30 km/h is reached by the leading TU at five points around DF. The points are reported in the text box of the following figure.

Fig. 20 shows the comparison between REF and DSP systems for the five different positions above and for different train-consists. In this figure, DPS operates with a stepwise reduction of pressure in brake pipe.

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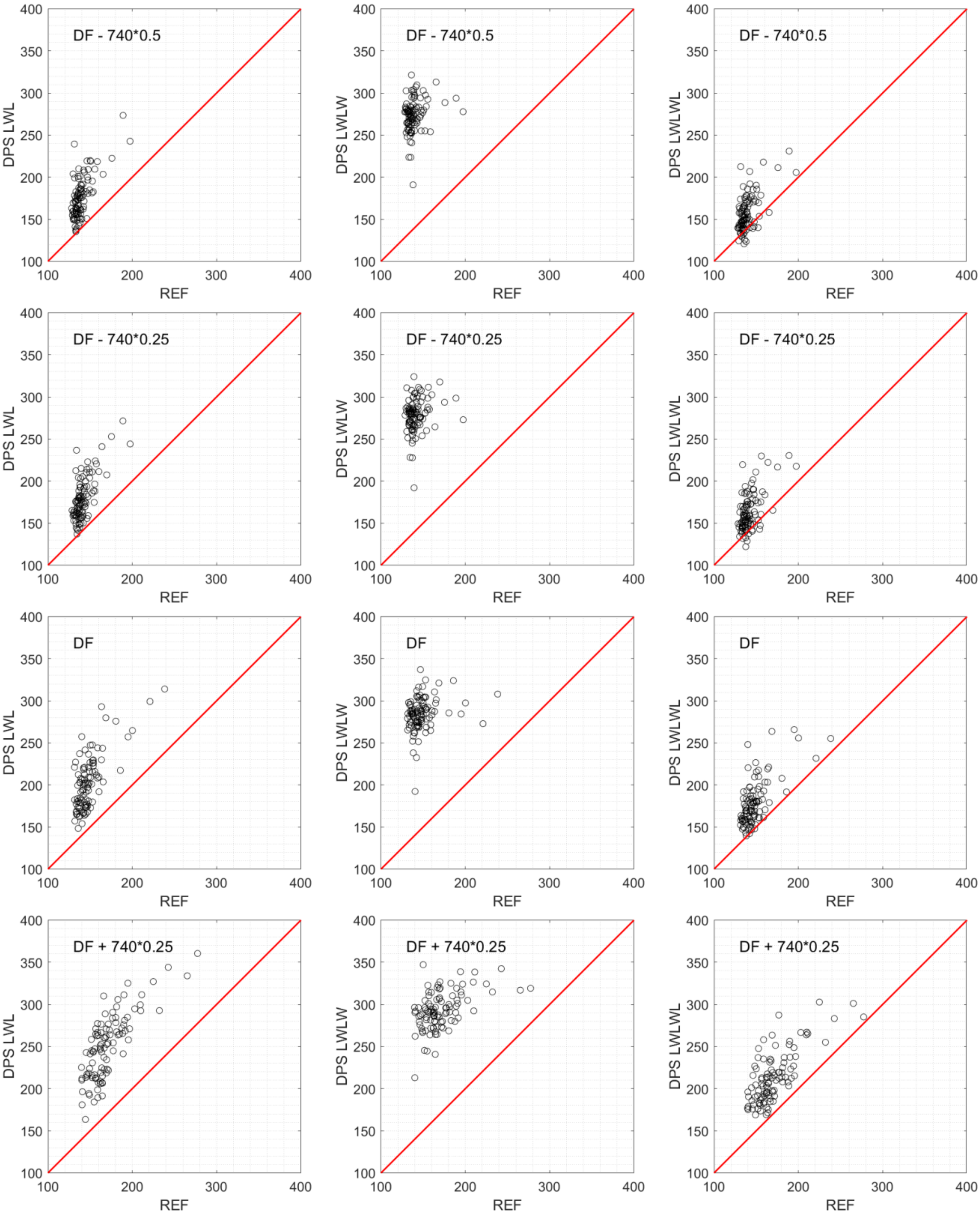

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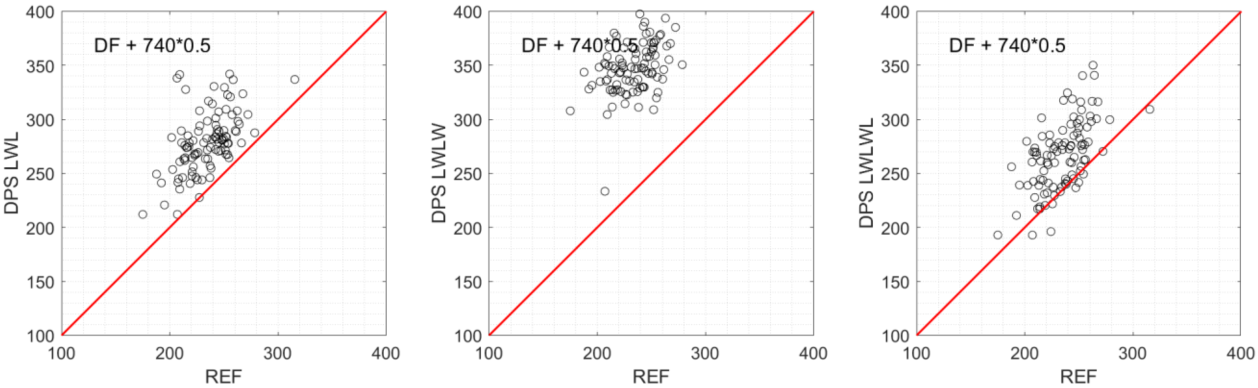


Fig. 20 Different applications of 6x1x, close to point DF.

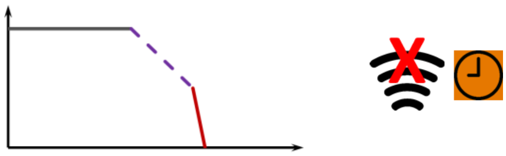
Fig. 20 allows the following statements:

- LCF are lower than those of train operations 5xxx and 9xxx and (in general) like than those of train operation 6x0x. As before, they do not exceed 400 kN which is considered a "safe" value for Longitudinal Compressive Forces according to UIC Leaflet 421 [2].
- LCF are bigger for DPS system than for REF system. As before, the reason is the removal of ED brake because of radio communication loss. This topic is further addressed in subsection 11.1.

Results of the last two subsections suggest to not remove the ED brake just because of a radio communication loss.

9.5. Train operations 7xxx and 8xxx

The pictograms used for this type of operation are:



These two train operations are similar, the only difference is that the leading Driver commands a service braking with target pressure in brake pipe equal to 3.5 bar, in 7xxx, and an emergency braking in 8xxx. In both cases, the communication loss occurs at the same time when the leading Driver is commanding the braking, and, in both cases, the *initial* condition considered here is a fully applied ED brake, as in 6xxx.

For these types of trains analysed here, the application of a full-service braking by the leading Driver results in *slightly* (less than 20 kN) higher LCF than the application of an emergency braking, considering the worst LCF.

For the sake of conciseness, the results are not reported for different points on the track, but only for the condition in which the leading TU reaches maximum speed when it is located in "DF": in this point, communication loss occurs, and one part of the train is downhill and the other is on a "flat" line.

Differently from previous cases, the effect of a different removal gradient for the ED brake on guided TU is considered: 30 kN/s (as in previous cases) and 7.5 kN/s. Fig. 21 shows a one-to-one comparison of LCF for REF and DPS. From these results, it is possible to say that:

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- LCF are lower than those of train operations 5xxx and 9xxx; they are like those of train operation 6x0x.
- LCF are bigger for DPS system than for REF system, except for LWLWL train consist. Reduction of gradient from 30 kN/s to 7.5 kN/s is beneficial only for some train consists: for LWLW seems beneficial a high gradient.

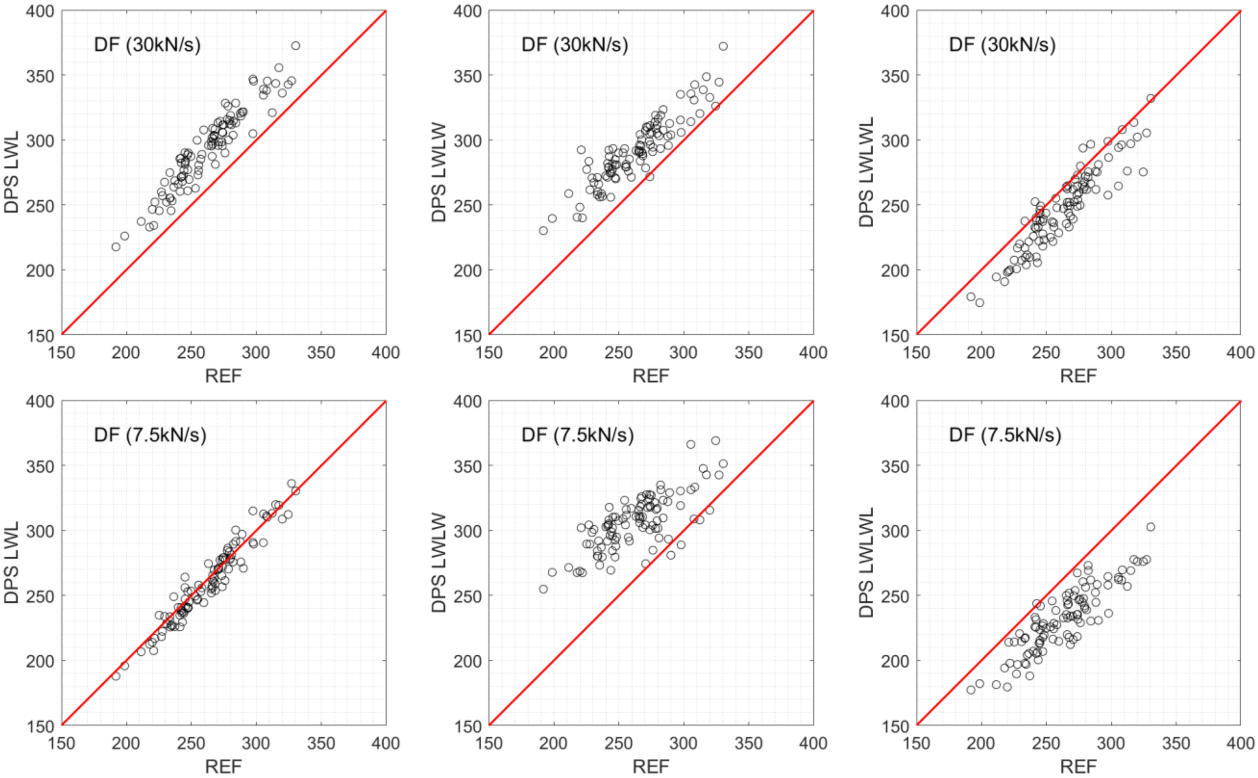

Fig. 21 Different applications of 7x0x, at point DF and different removal gradient for ED brake.

Results of Fig. 21 show that the gradient of ED brake removal should be set according to the position of the guided TU within the train consist. Of course, a dedicated study is needed to proper address (optimize) this topic and this is beyond the scope of M2O.
Anyway, a gradient of ED brake removal must be set, since in case of radio communication loss, the leading Driver can command the release of ED brake at guided TU just by giving a first application step (target pressure in brake pipe equal to 4.5 bar).

10. Driver intervention

In this section, for the most dangerous train operations a further set of simulations is performed. In this section, a particular DPS failure is assumed: i.e. not only there is a radio communication loss, but the DBCU is not able to detect the first pressure drop of 0.2 bar. In this circumstance, that can occur only during the tests and or with an acceptably low probability when the solution is commercialized (because of the implementation of the appropriate SIL levels), the preliminary lack of safety is compensated by the presence of the Driver, on board. In this train operation, the Driver

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must be instructed to perform an emergency braking when there is a pressure drop and the DBCU does not intervene automatically. In this section, it is assumed that an emergency braking is commanded as soon as the pressure at guided TU reaches 4.5 bar (equivalent to a pressure drop of 0.5 bar) and the DPS was not able to detect the pressure drop of 0.2 bar. This condition will be further analysed in D3.2. The results of this section will prove that, even in this condition, which will not to be reproduced experimentally, the DPS system is *usually* safer than the REF system.

10.1. Train operation 5xxx

During this train operation, if DPS fails, the Driver on the guided TU performs an emergency braking when the pressure drop is 0.5 bar. It is assumed that the DPS fails just on one TU in train-consist LWLWL 

; the failure on both TU is not considered.

Fig. 22 reports the traction force at the TU, along with the train speed, on the right and the pressures in brake pipe and in the brake cylinders for the TU on the left, for reference and DPS systems. A vertical line to indicate the moment of initial communication loss (C.L.) is also displayed. For reference system, the power is reduced when there is a pressure drop of at least 0.4 bar (miming an interlock, 0.5 bar is used) and the emergency braking is commanded if the pressure in brake pipe at the second TU reaches 3.5 bar: this condition is the same of subsection 8.3 and it is reported here just to ease the Reader. As said before, Driver performs an emergency braking (which cuts off the power) when the pressure drop at guided TU is 0.5 bar. For LWLWL train consist, only one TU has a total DPS failure.

Fig. 23 reports a comparison among the reference system and the three different DPS train-consists: the LWL train consist is skipped since it behaves as the reference system, even if the pneumatics is different. This should not surprise since the maximum LCF occurs few second after the emergency braking commanded by the leading TU: the subsequent emergency braking commanded by the guided TU occurs when the maximum LCF has been already reached. Figure shows that the DPS system is better than the REF system even if there is a total DPS failure on one TU.

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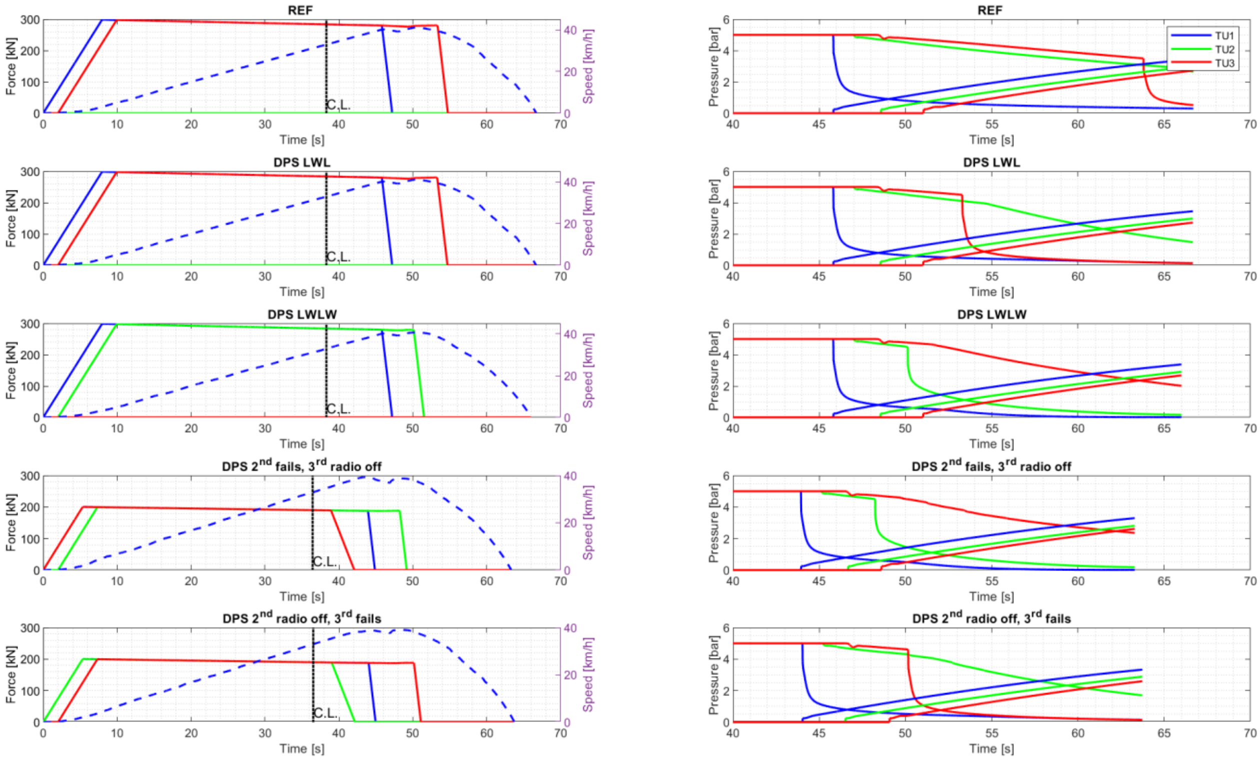

Fig. 22 Mechanical and pneumatic parameters for 5xxx  *. For readability sake, legend is reported just one time, but it applies to all sub-plots.*

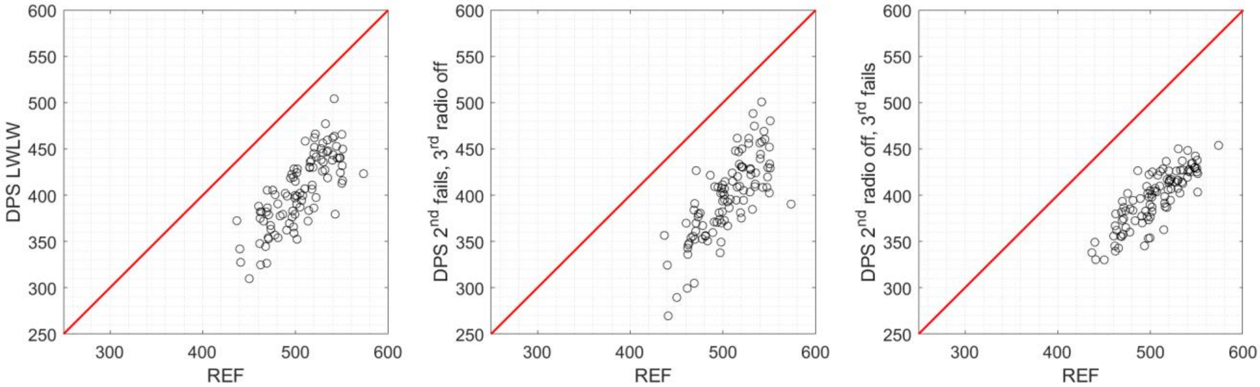

Fig. 23 5xxx  *, one to one comparison of LCF.*

10.2. Train operation 9xxx

During this train operation, if DPS fails, the Driver on the guided TU performs an emergency braking when the pressure drop is 0.5 bar. As before, it is assumed that the DPS fails just on one TU.

Fig. 24 is the counterpart of Fig. 22. Fig. 24 reports a comparison among the reference system and

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the three different DPS train-consists: the LWL train consist is skipped since it behaves as the reference system, not surprisingly. Figure shows that the DPS system is *usually* better than the REF system even if there is a total DPS failure on one TU. Even if in some cases the DPS system is worse than the REF system, the LCF forces are high, but not exceptionally high as those measured experimentally by FFL4A in May 2019. This suggests executing the train operations 9xxx on an area with good radio coverage and/or on a railway track section with high (> 400 m) radii of curvature.

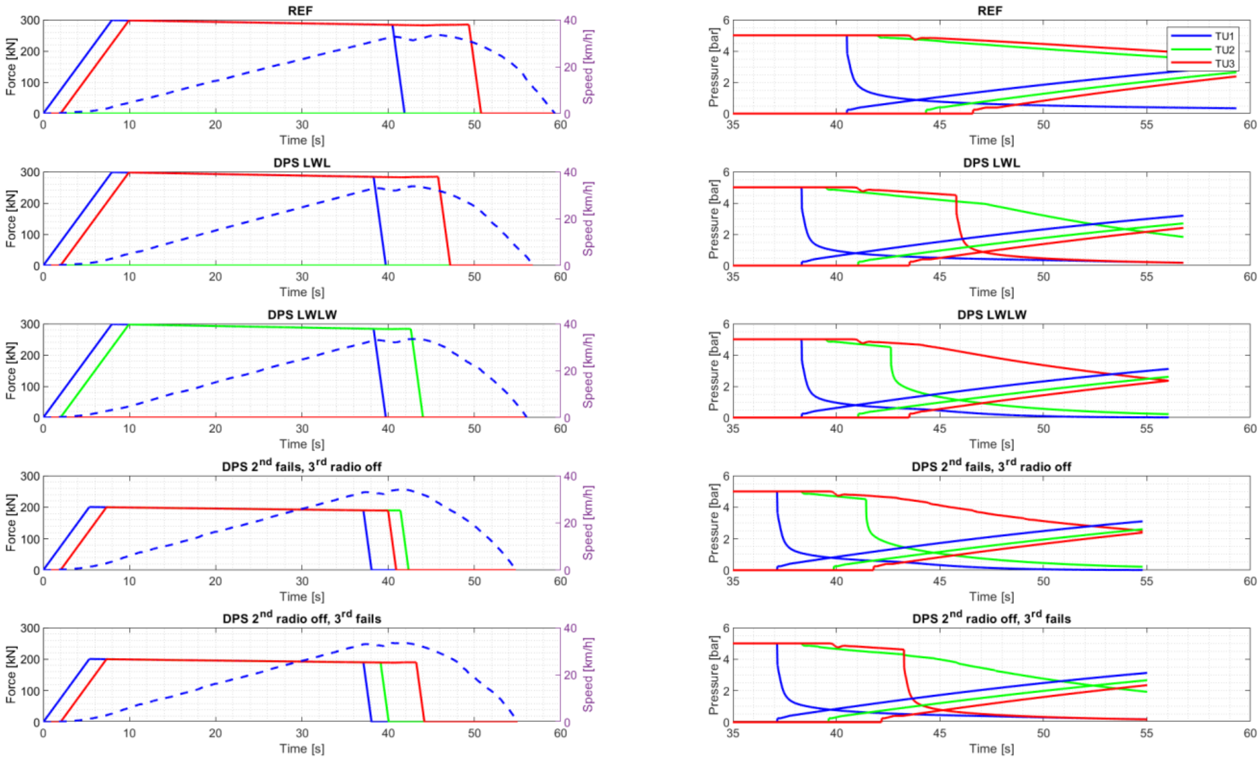

Fig. 24 Mechanical and pneumatic parameters for 9xxx  *. For readability sake, legend is reported just one time, but it applies to all sub-plots.*

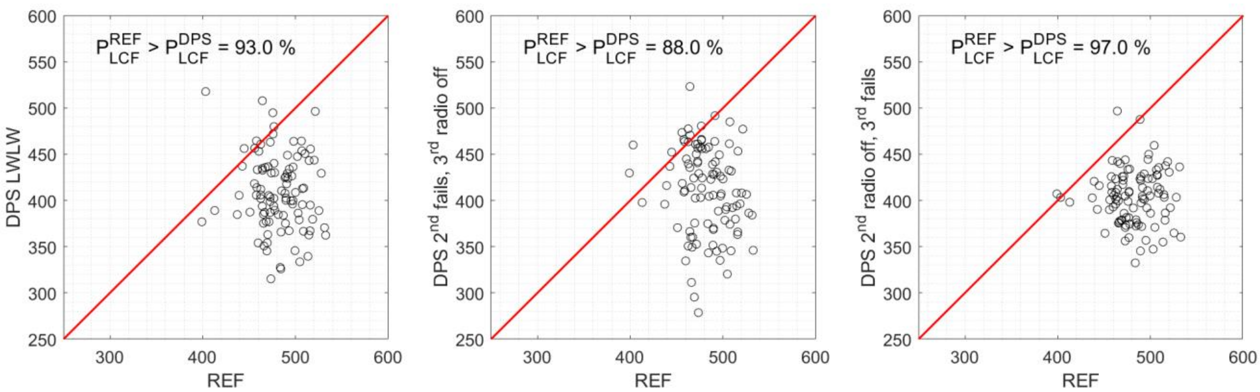

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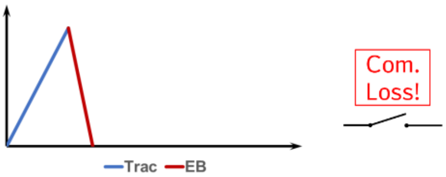
Fig. 25 9xxx *, one to one comparison of LCF.*

11. Parametric studies to improve DPS

In this section, the results of two studies are reported. The first is on the effect of time interval for radio communication loss on LTD: the test used is the 5xxx. The second is about the two possible behaviours of the DPS when a pressure drop of 0.2 bar is detected and there is a radio communication loss: in these occasions, the brake pipe is a sort of radio back-up and DPS can reduce the pressure stepwise or by a full-service braking. The train operation used for the second study is 9xxx.

11.1. Time of radio communication loss for automatic TU intervention

The pictograms used for this type of operation are:



In this train operation, the communication loss occurs during the acceleration three seconds after 30 km/h are reached and *before* the driver, on the leading TU, performs the emergency braking.
Standard DPS settings impose a traction removal that is modelled with a gradient of 60 kN/s when the time interval of communication loss equal to 2.5 s is reached. In this subsection, this time interval is changed from 1.5 s to 10 s.
Fig. 26 reports the value of LCF using the statistical value of $|\mu_{LCF}| + 3\sigma_{LCF}$ for each time interval and different train consists. According to these results, there is no benefit in removing traction even if there is a radio communication loss: it is necessary to do so when (and if) the pressure at guided TU reduces by 0.2 bar. This result is of paramount importance for the availability of the train and it is in line with former results of FP7 Marathon. In the light of these results, the worse behaviour of DPS trains in manoeuvres 6xxx with respect to REF trains does no more worry.

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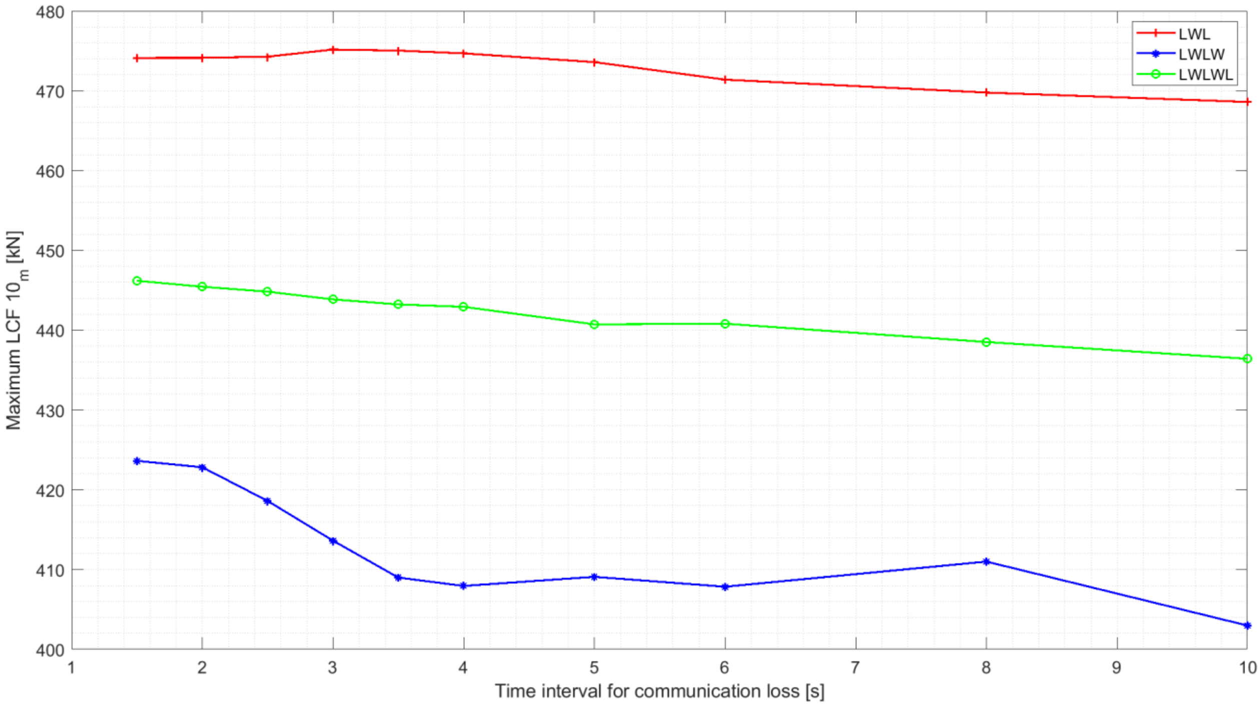

Fig. 26 5xxx, effect of time interval for communication loss in terms of maximum LCF ($|\mu_{LCF}| + 3\sigma_{LCF}$)

11.2. Stepwise reduction of pressure VS full-service braking

The results of previous pages have shown that if the DPS reacts performing a full-service braking when the pressure drops by 0.2 bar at the guided TU, during a communication loss, is better than performing a stepwise pressure reduction, in the same conditions. Anyway, it has been also proved that the difference in terms on LCF is minor.

In this subsection, the performance of DPS train consists is studied when the leading TU does not apply an emergency braking (as before), but just a first-application step (target pressure in brake pipe is 4.5 bar). The train operation is of type 9xxx, i.e., a full acceleration followed (in this case) by a first application step braking, commanded by the leading TU. In this train operation, the communication loss occurs *when* (i.e., at the same time) the Driver on the leading TU performs the emergency braking.

Fig. 27 reports a one-to-one comparison: first row refers to LCF and second to LTF. This figure shows that there are no substantial differences among the two behaviours of DPS in terms of LCF, but the differences arises only for LTF. Stepwise reduction of pressure is associated to lower values of LTF with respect to full-service braking for this type of manoeuvre. The results show that, especially for DPS LWL train consist the LTF can bring to a potential train disruption: this advice to implement the stepwise pressure reduction instead of the full-service braking upon detection of pressure drop in brake pipe, in case of radio communication loss.

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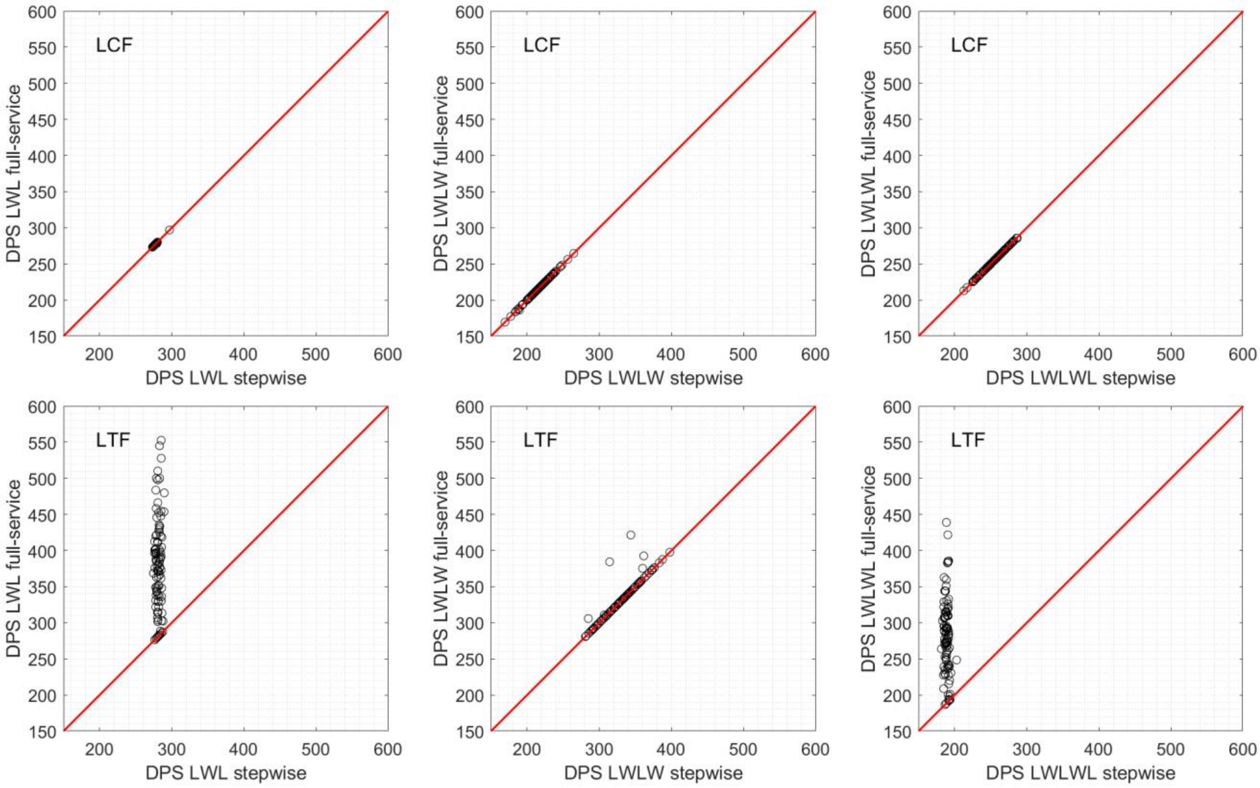
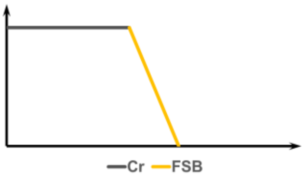
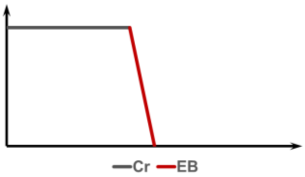


Fig. 27 One to one comparison of DPS train consists: first row refers to LCF and second row to LTF.

A second study is also reported here; this study deals with the stopping distance. Changing the initial train speed from 80 km/h to 100 km/h (step 10 km/h), the stopping distances are computed for REF and DPS train consists, considering a full-service braking 

and an emergency braking 

, in case of radio communication loss 
. Computation of the stopping distance for DPS trains has been performed considering a stepwise pressure reduction or a full-service braking. In all cases the DPS trains stop before the REF trains (in a one-to-one comparison).

Fig. 28 reports the relative percentage difference between the main stopping distance of REF trains and the different DPS train consists; positive values mean that the stopping distance of REF trains is bigger than the DPS counterparts. First row refers to a full-service braking from coasting (or cruising) conditions; second row to an emergency braking application. Results on the left refers to a stepwise pressure reduction, whereas results on the right to a full-service braking. The latter behaviour of DPS guarantees shorter stopping distances, of course, but has some drawbacks, as it

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has been shown before.

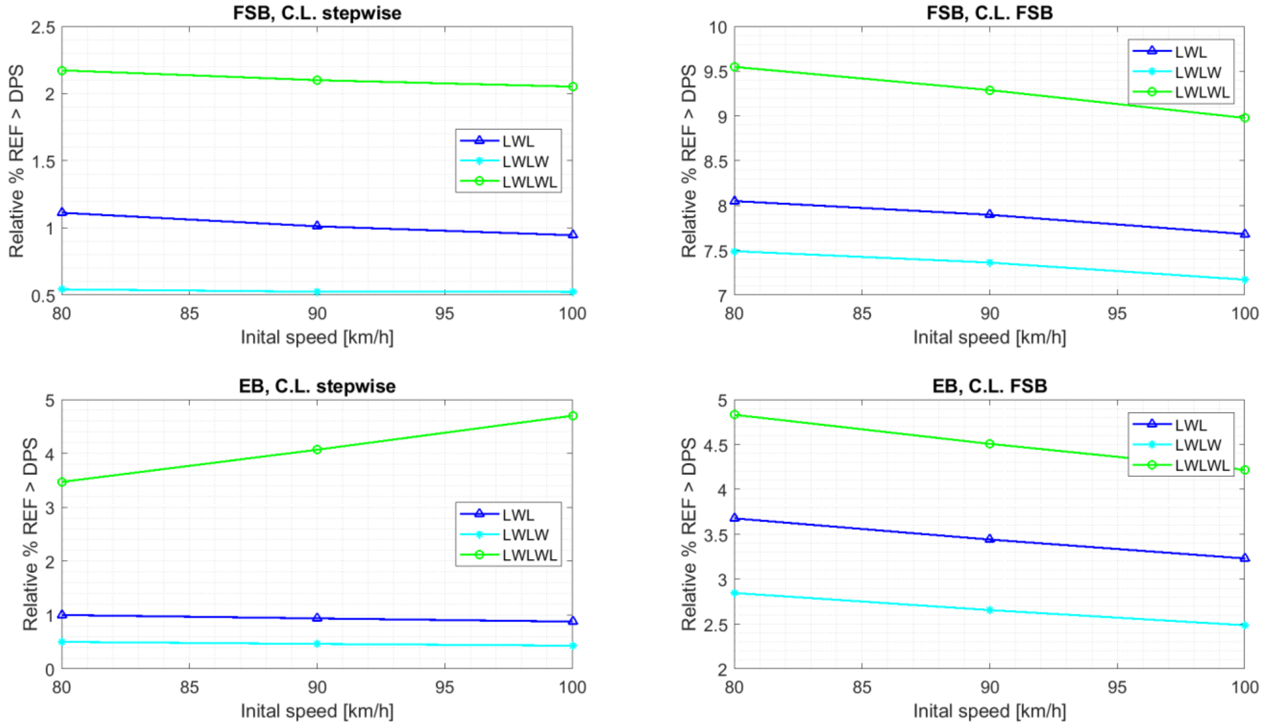

Fig. 28 relative percentage difference between the main stopping distance of reference trains and the DPS counterparts, for different manoeuvres.

Results of Fig. 28 allows to conclude that the application of a stepwise reduction of pressure in brake pipe provides average stopping distances lower than the reference case.

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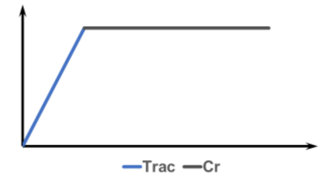
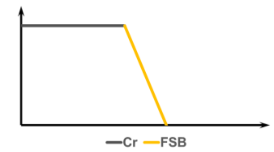
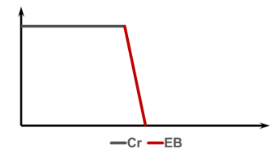
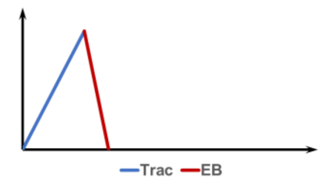
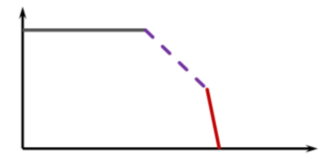
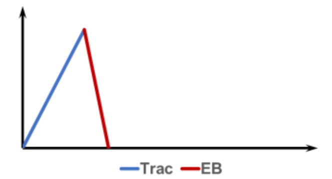
12. Conclusions

The table below represents a summary of the simulations performed in this deliverable with some comments on the achieved results.

<table>
<tr><th colspan="2">Train operation</th><th>DPS status</th><th>Comment/outcomes</th></tr>
<tr><td>1xxx</td><td></td><td rowspan="4"></td><td>DPS better or equal to REF, except for LTF of LWL train consist -Fig. 3 (a)-</td></tr>
<tr><td>2xxx</td><td></td><td rowspan="2">DPS better or equal to REF -Fig. 3 (b) and (c)-</td></tr>
<tr><td>3xxx</td><td></td></tr>
<tr><td>4xxx</td><td rowspan="3"></td><td>DPS better or equal to REF, except for LTF of LWL train consist -Fig. 5-</td></tr>
<tr><td rowspan="2">5xxx</td><td></td><td>DPS better than REF -Fig. 8 (planar)- -Fig. 15 (Up/Downhill)-</td></tr>
<tr><td></td><td>DPS better than REF -Fig. 23-</td></tr>
<tr><td>6xxx</td><td rowspan="3"></td><td></td><td>On Up/down-hill track. DPS worse than REF but LCF forces are "low" -Fig. 18-</td></tr>
<tr><td>7xxx</td><td rowspan="2"></td><td rowspan="2">On Up/down-hill track. DPS worse than REF but LCF forces are "low" -Fig. 22- Reducing the removal gradient is beneficial.</td></tr>
<tr><td>8xxx</td></tr>
<tr><td rowspan="2">9xxx</td><td rowspan="2"></td><td></td><td>DPS better than REF -Fig. 11 (planar)- -Fig. 16 (Up/Downhill)-</td></tr>
<tr><td></td><td>DPS is usually better than REF -Fig. 25-</td></tr>
</table>

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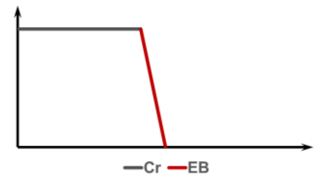
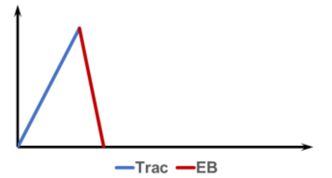
10xxx			DPS is better or equal to REF for LTF; LCF are of no concern. -Fig. 12 (a)-
			DPS is better or equal to REF for LTF; LCF are of no concern. -Fig. 12 (b)-

The main conclusion of this deliverable is that DPS train is always better than REF train in nominal conditions, with respect to LCF. When there is a radio communication loss, the DPS train is usually better than the REF train with respect to LCF: the scenarios in which this conclusion is not valid are reported in sections 9.3 and 9.4, when the train is initially braking with ED brake. The gradient removal of ED brake is a parameter that affects the LCF: anyway, the LCF that arise in these train operations are much lower than the LCF experienced in other train operations (e.g., 5xxx and 9xxx). Moreover, these train operations assume an ED brake removal after 2.5 s of radio communication loss: the results of section 11.1 prove that there is no need to change the TU "status" (whichever traction or braking) because of a communication loss, unless a pressure drop is detected in brake pipe.
Above conclusions do not depend on the track gradient, i.e., the DPS train is better than the REF train with respect to LCF, even if the LCF values depend on the track gradient.
From these analyses, it is advised to test the DPS system considering:

- different gradients of ED brake removal
- different time intervals for the automatic reduction of the traction force (or braking force), in case of radio communication loss before any detection of pressure drop in brake pipe.

Moreover, since deliverable 3.1 [1] has proved (in one simulation) that the full-service braking is the best behaviour of DBCU, when the pressure drop of 0.2 bar is detected, these two options are analysed in this deliverable:

- Full-service braking when the pressure drop of 0.2 bar is detected.
- Stepwise pressure reduction when the pressure drop of 0.2 bar is detected (as in FFL4E).

The results of Fig. 8 and Fig. 11 prove that above conclusion is true, but the benefits of a full-service braking are minor (in terms of LCF reduction). On the contrary, the results of Fig. 27 prove that if the leading Driver commands just a first application step, the automatic full-service braking commanded by the guided TU leads to high Longitudinal Tensile Forces (LTF) capable to damage the couplings. For these reasons, it is suggested to test both the behaviours of DBCU during the test trials.
Finally, since the TRL of the devices designed by FR8RAIL II Partners is 5, it is important to test them in a condition in which the Driver can intervene in case of necessity, as done in May 2019 for the FFL4E tests. The section 10 is dedicated to this issue and it shows that for 5xxx tests the DPS is

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better than REF, whereas for 9xxx this is true with a high percentage of occurrence. For the test trials it is advised to execute these simulations when the train consist is fixed to see if the Driver intervention allows a level of LCF for DPS train lower than the corresponding level of REF train. Furthermore, it is necessary to execute final simulation runs on the specific test demonstrator and in the specific conditions that will be tested by FR8RAIL II Partners. At this aim, the D3.2 will contain these simulations which will be further considered in D4.1. It is necessary to simulate the condition in which the DPS does not react to a pressure drop in brake pipe of 0.2 bar and for which it is requested the Driver intervention.

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13. References

[1] Cantone L, Toubol A 2020 *D3.1 – M2O LTD Simulations Report*, https://www.marathon2operation.eu/web/pdf/M2O_D3.1_LTD_simulations_report_final.pdf

[2] Leaflet UIC 421, Rules of the consist and braking of international freight trains, 9th edition, January 2012.