

MARATHON 2 OPERATION (M2O)

Simulations, sensitivity analysis, 2, 3 and 4 locomotives and up to 1500m trains, randomly loaded. Simulations for experimental test campaign (2021)



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Grant Agreement
Number **826087**



Why a sensitivity analysis is needed?

TrainDy is the UIC approved software currently used to address the Longitudinal Train Dynamic (LTD).

PNEUMATIC
PROBLEM



MECHANIC
PROBLEM



A great number of parameters are involved!



A sensitivity analysis has been proposed to augment the trustworthiness of TrainDy simulations and their extrapolation potential:



- to identify the key parameters driving the LTD
- to identify interactions among parameters
- to compare long trains with shorter ones

Technical Vs Operational train parameters

DEFINITION	DESCRIPTION	RAILWAY UNDERTAKINGS CONTROL	UNCERTAINTY	EXAMPLES
Technical parameter	Intrinsic train characteristic	Virtually no control on it (or very limited)	“physical” small uncertainties due to tolerances, manufacturing, measures, aging, etc.	<ul style="list-style-type: none"> - Brake pipe diameter - Initial pressure in brake pipe
Operational parameter	Controlled train or track characteristic	Full or partial control on it	They can experience significant variations and set different braking simulations scenarios.	<ul style="list-style-type: none"> - Track characteristics - Train system setting

N.B. The line that divides technical from operational parameters is blurred and ultimately depends on the analysis context.

Emergency braking starting speed



TECHNICAL PARAMETER

Speedometer reading
uncertainty $\pm 3\%$

OPERATIONAL PARAMETER

Different maneuvers at
30Km/h or 60Km/h



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Reference maneuvers

**Braking
from
cruising (EB)**

Constant speed 30Km/h



Emergency Braking



De facto, the maneuvers are special Operational Parameters.

**Braking from
full traction
(T-EB)**

Acceleration from 0Km/h up to 30Km/h

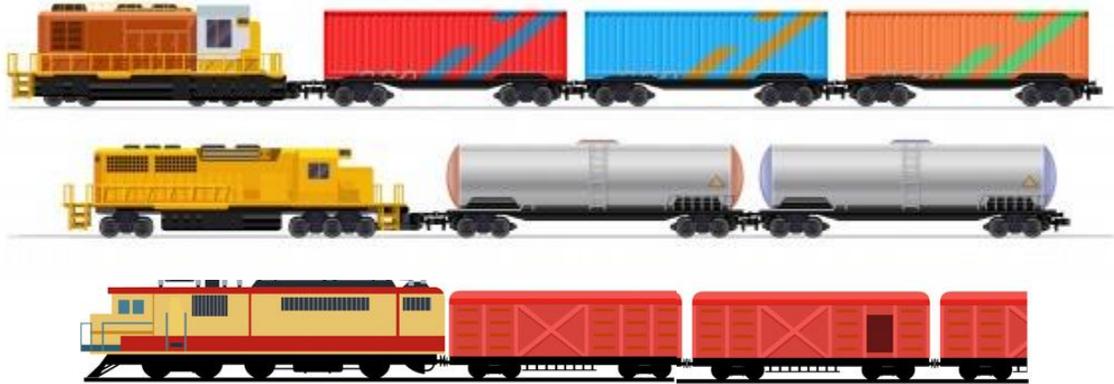


Emergency Braking



Reference trains family

FREIGHT TRAINS POPULATION



Differences:

- Total length
- Load distribution
- Type of Wagons
- Etc.

Impossible to identify a single "Reference Train"

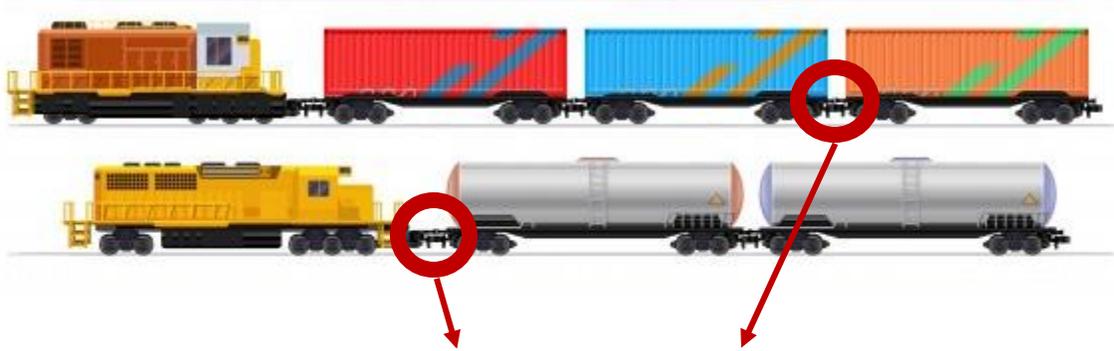
A "Reference train family" is statistically generated following the UIC Leaflet 421 flowchart

BASIC FAMILIES (1000 trains each):

- **H_740** – One train, hauled mass is between 2500t and 5500t;
- **T2_740** – First train has an average length 400m and hauled mass between 1200t and 1600t, second train has an average length of 300m and hauled mass between 800t and 1200t;
- **T4_1500** – 4 trains coupled together having each a hauled mass between 800t and 1200t. The overall train length is 1500m.

TrainDy results extraction: the CDF

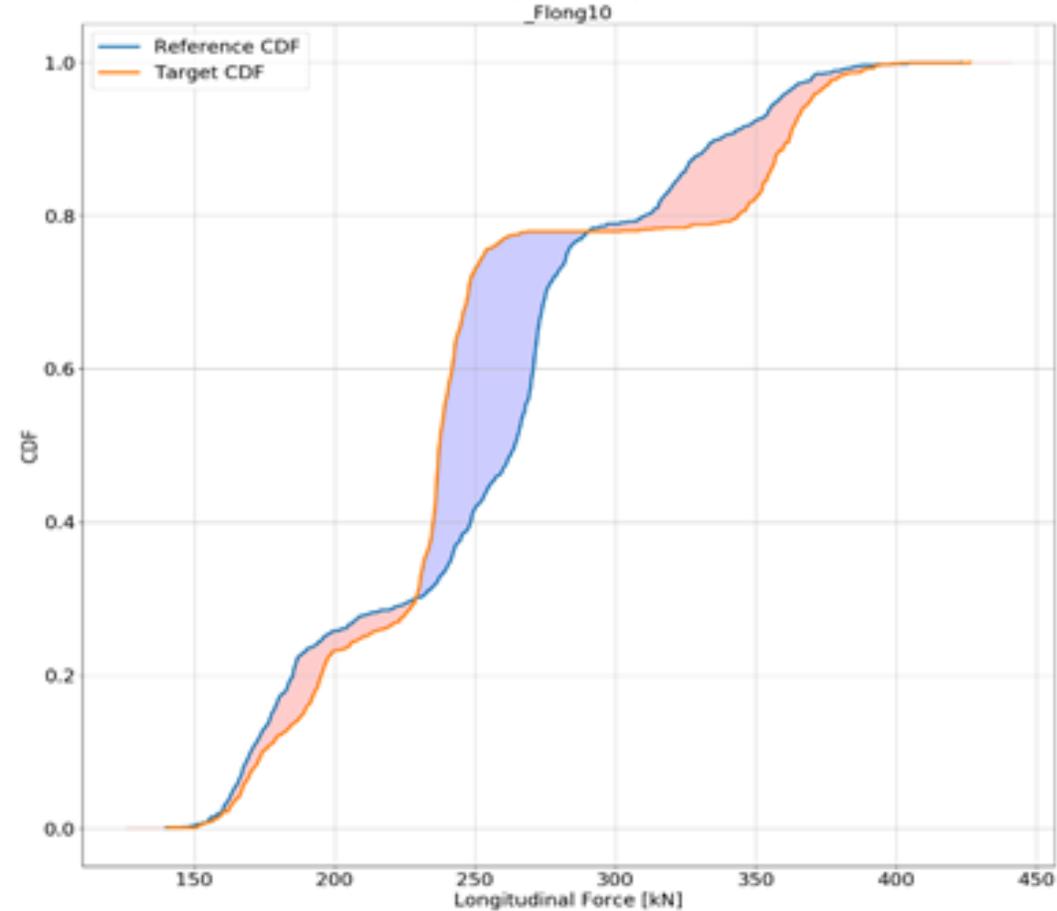
1000 TrainDy simulations
(one for each train in family)



Max Longitudinal force registered
among all train wagons and among
all time-steps for each train.

Both for traction and
compression forces

Cumulative Distribution
Function (CDF) of such forces.

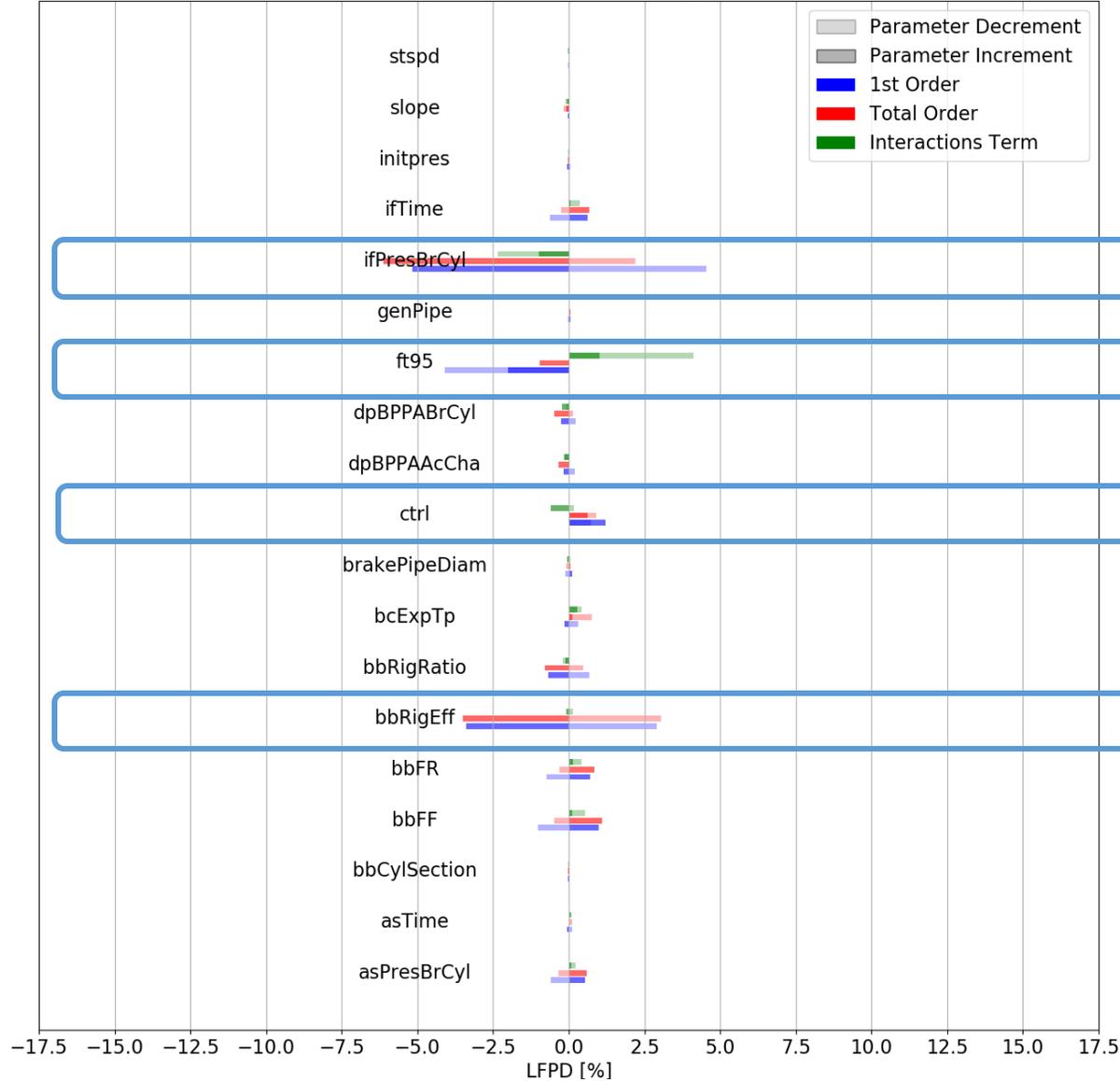


Results: Tornado Plots (1/3)

T2_740, EB

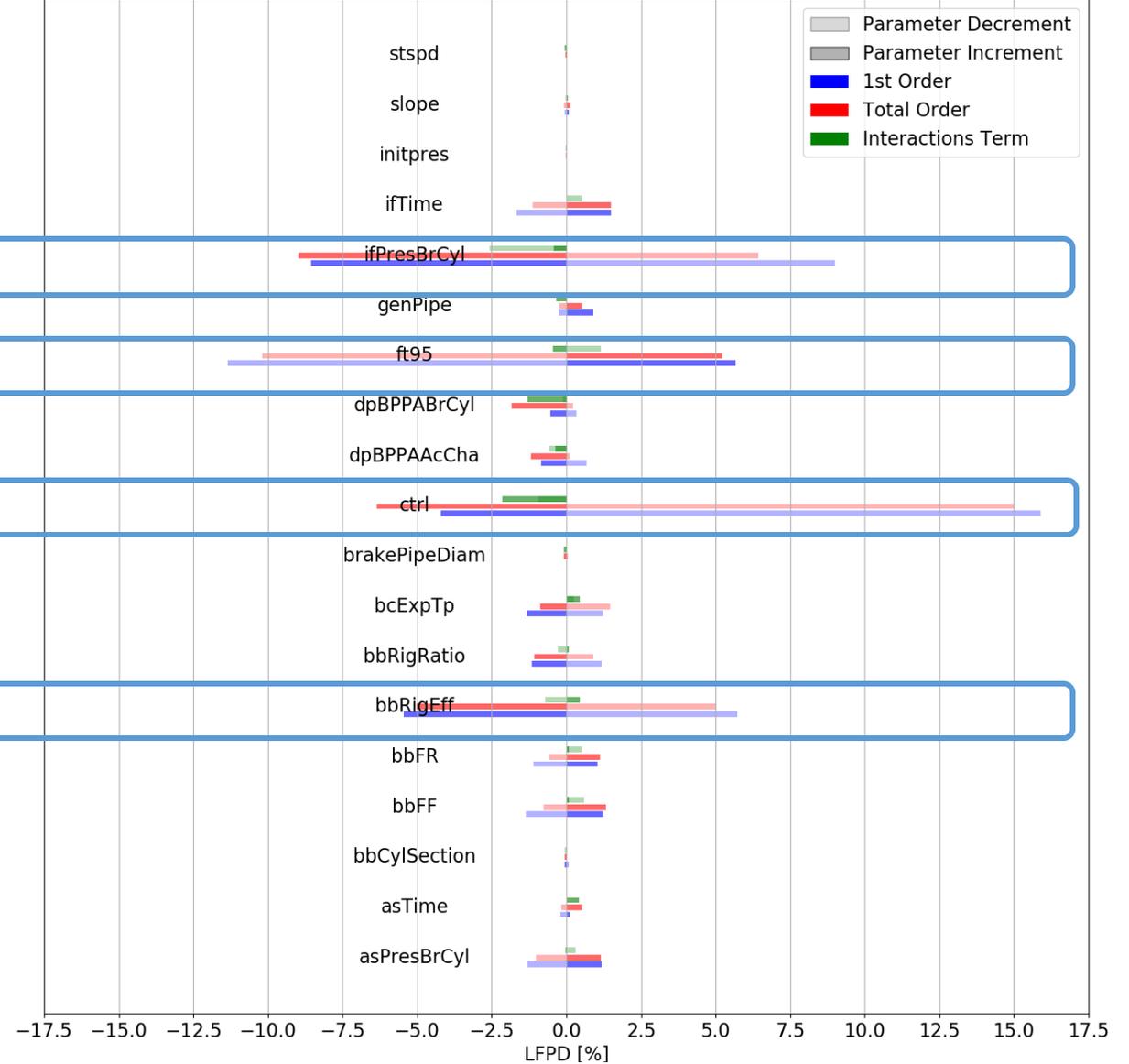
LTF

Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)



LCF

Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)

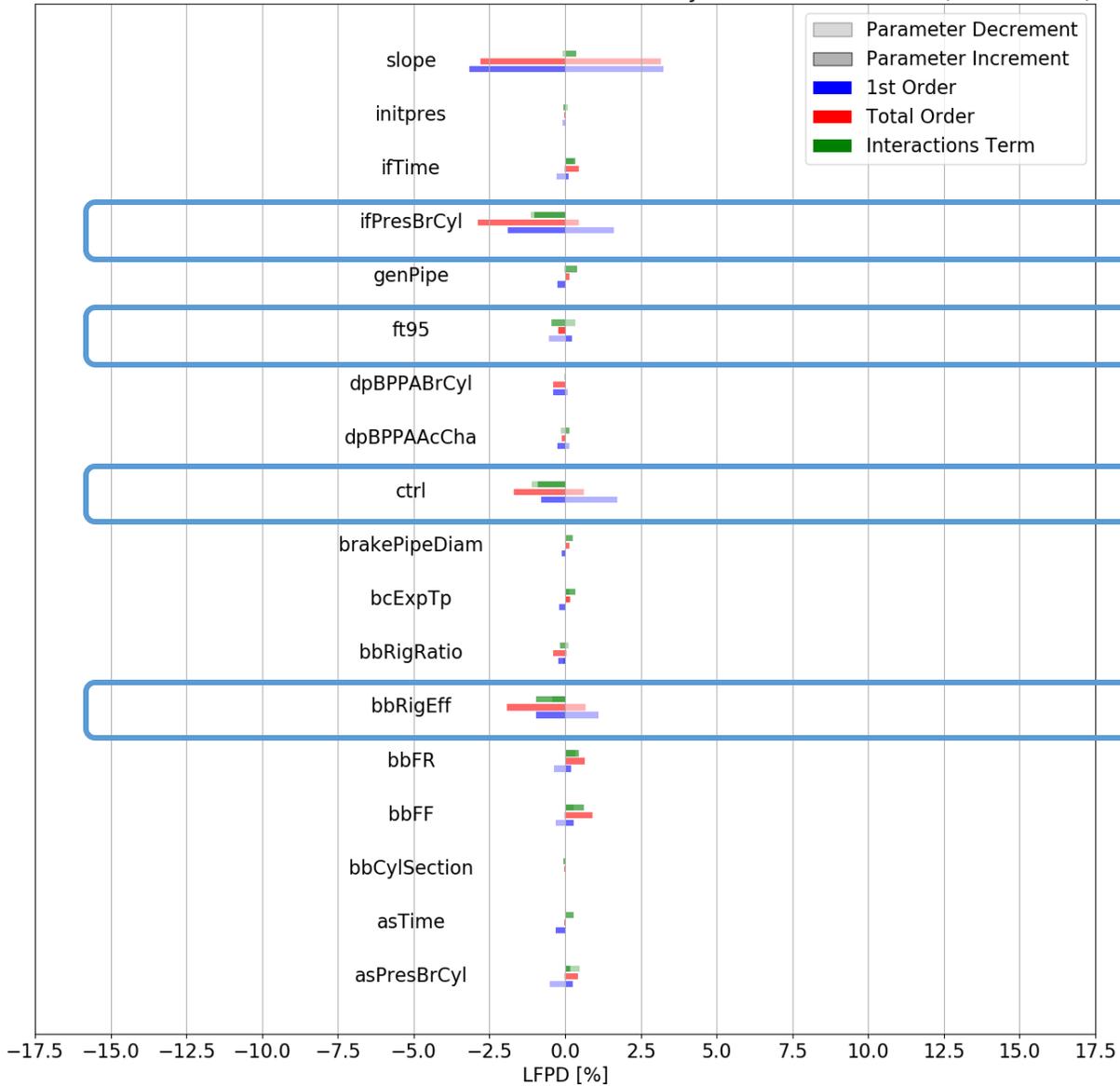


Results: Tornado Plots (2/3)

T2_740, T-EB

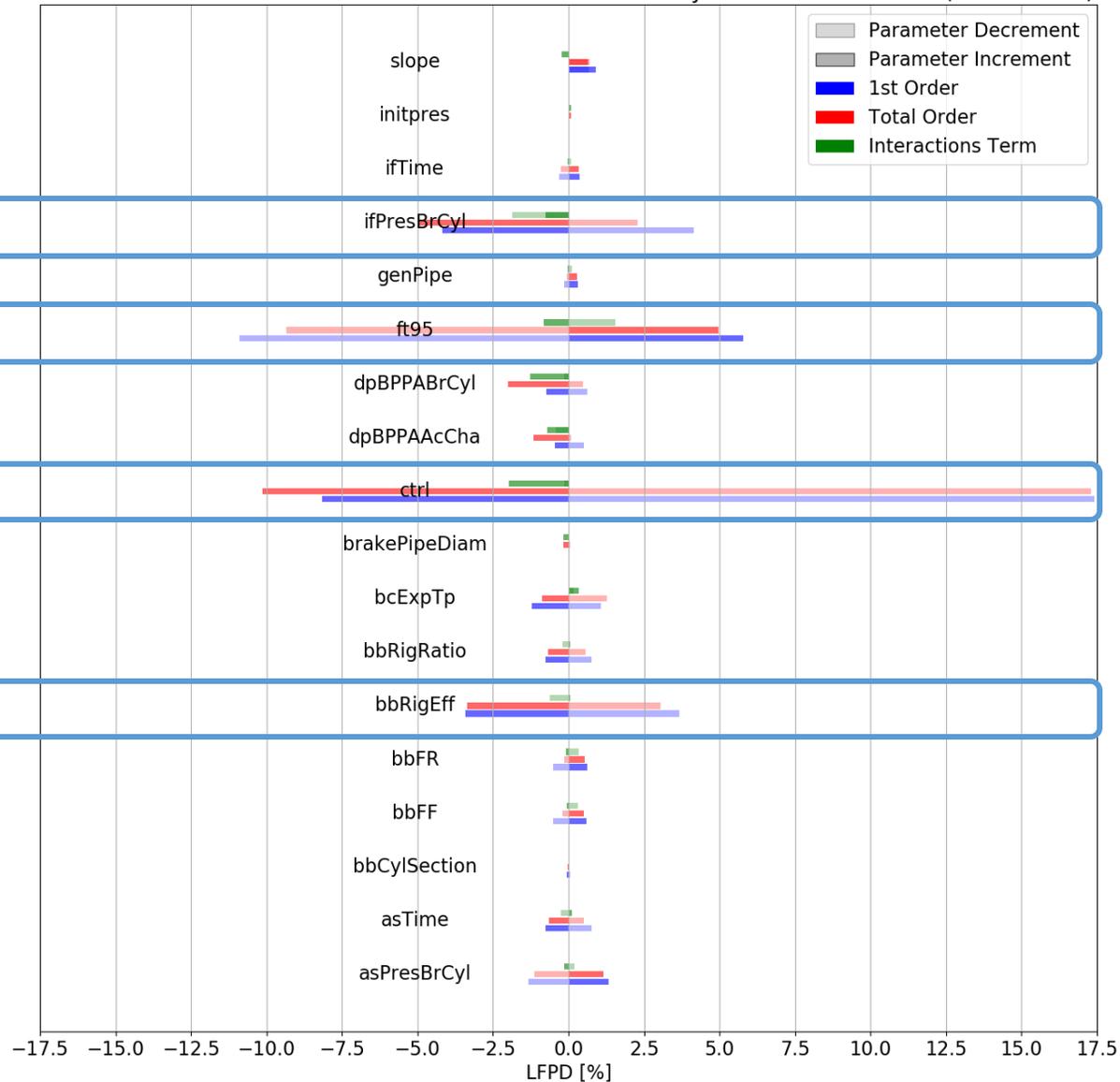
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Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)



LCF

Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)

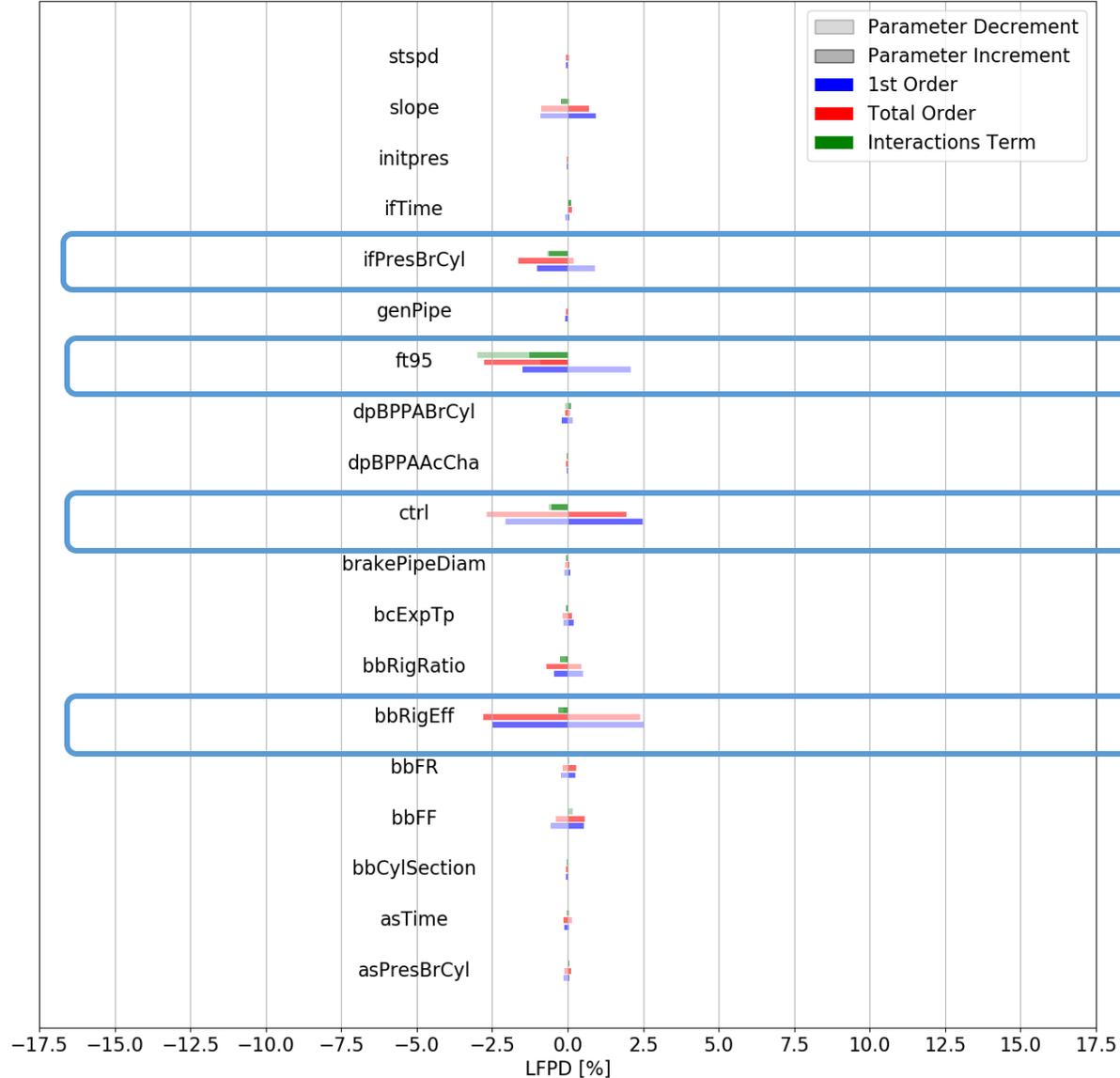


Results: Tornado Plots (3/3)

T4_1500, EB

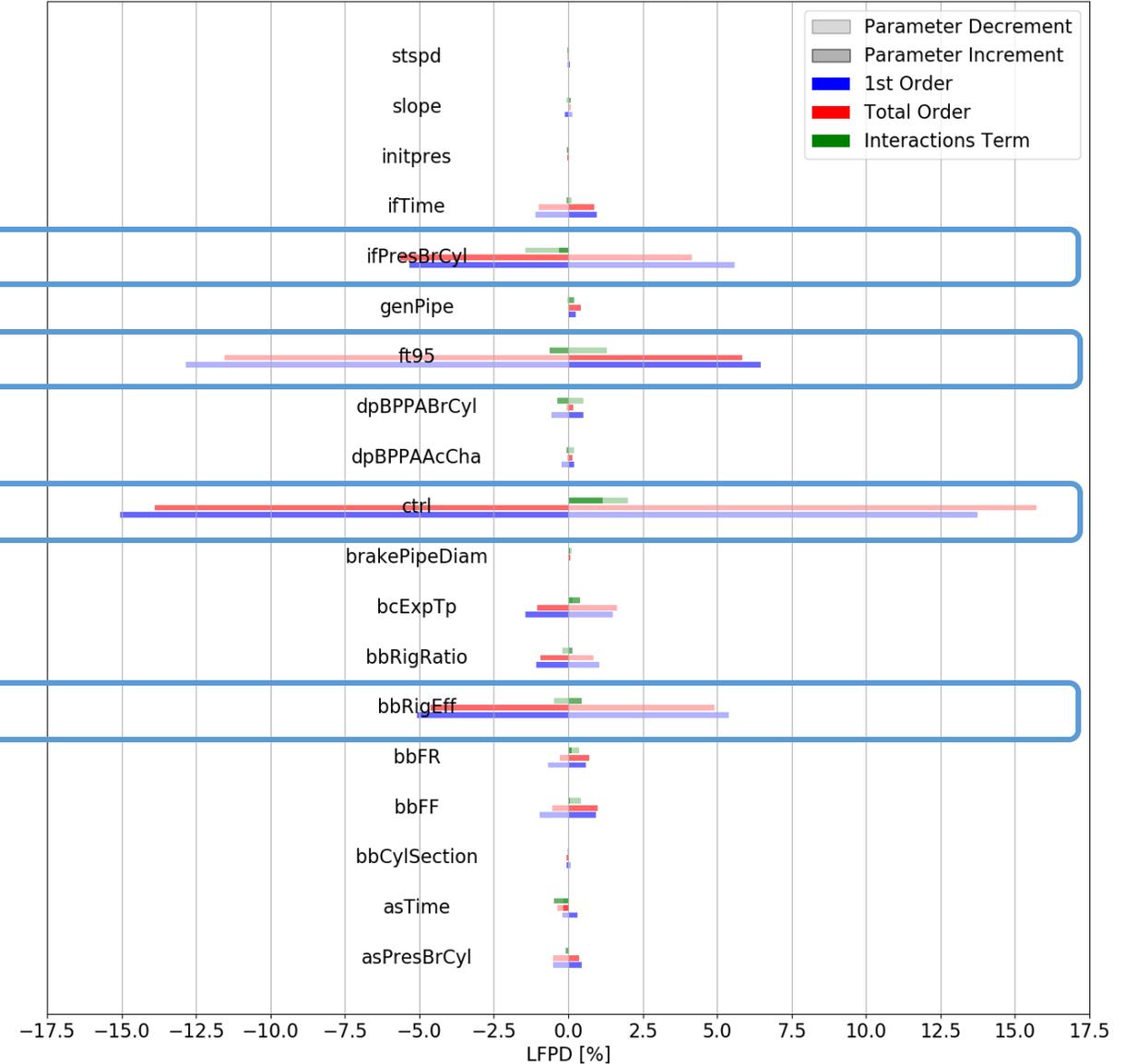
LTF

Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)



LCF

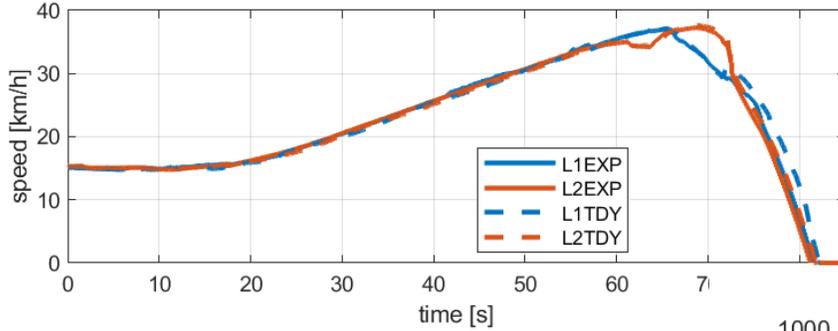
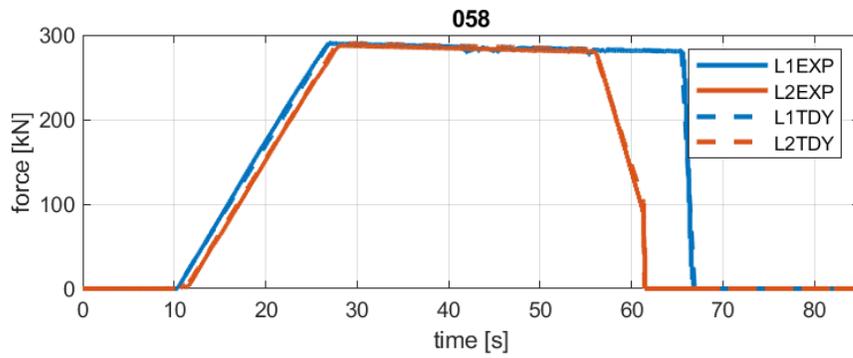
Tornado Plot: Parameters variation influence over TrainDy simulation outcome (LFPD based)



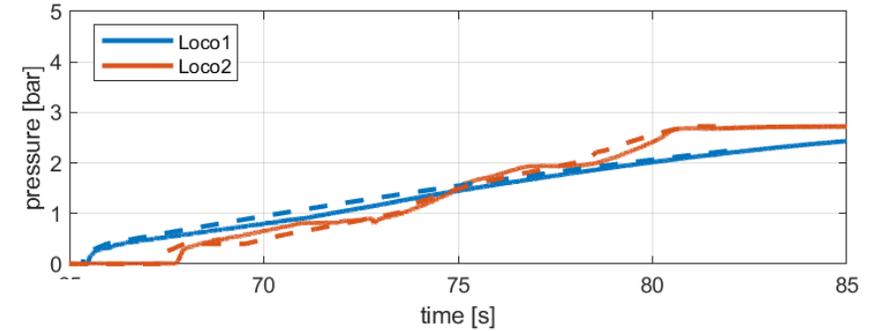
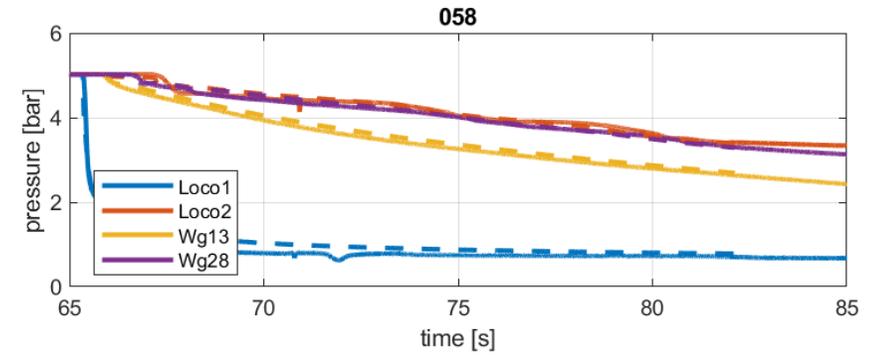
Maximum train length/hailed mass VS technology: number of TU, radio type (GSM-R, LTE), DPS parameters

- Current running trains: No DPS, no remote loco
- Randomly generated from real DB Cargo database.
- Hauled mass has been grouped: 0-800, 801-1200, 1201-1600, 1601-2500, 2501-4000 ton.
- Computation of virtual derailment and disruption probabilities for two manoeuvres:
 - emergency braking (EB), from 30 km/h
 - acceleration up to 30 km/h and emergency braking (T-EB)
- Admissible LCF follows UIC 421 and admissible LTF has been set to 550 kN.
- Derailment and disruption risks considering the different types of reference trains

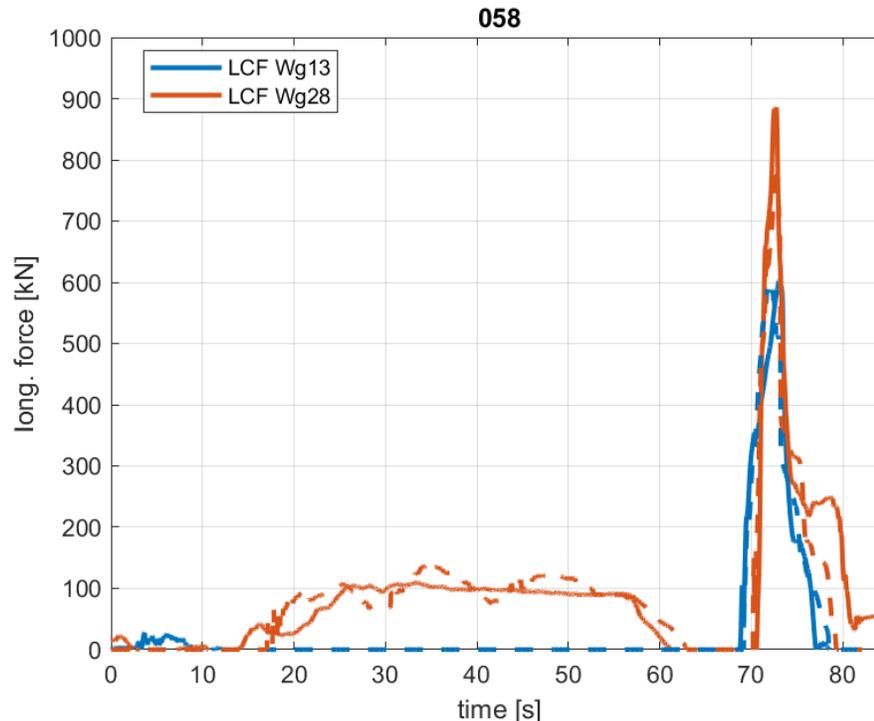
Train Operation	Derailment [%]	Disruption [%]
EB	1.94	0.38
T-EB	5.80	1.70



Solid line is used for measurements, dashed line for simulations.



Acceleration up to 30 km/h, loss of communication, reduction of traction from guided loco. Then, application of an emergency braking from the leading loco. Guided loco reduces the pressure in BP step-wise.



	Error [%]
Coupling 13	1.10
Coupling 28	10.68

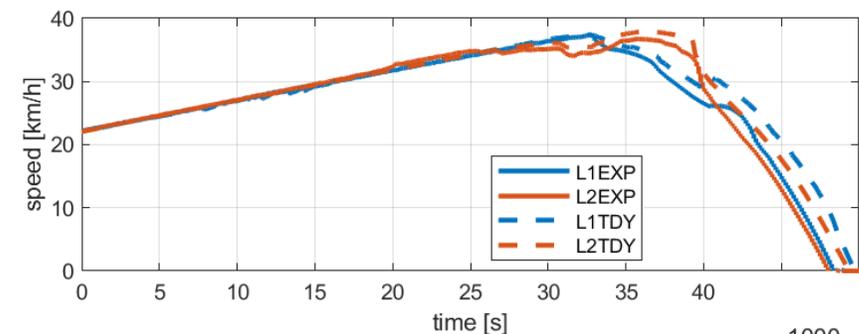
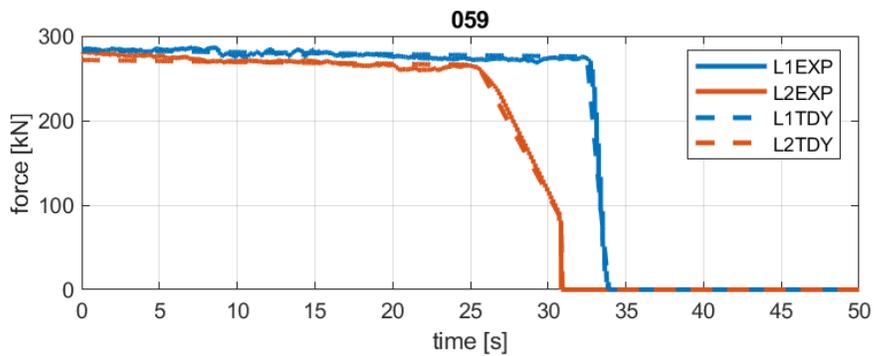
← Instantaneous forces



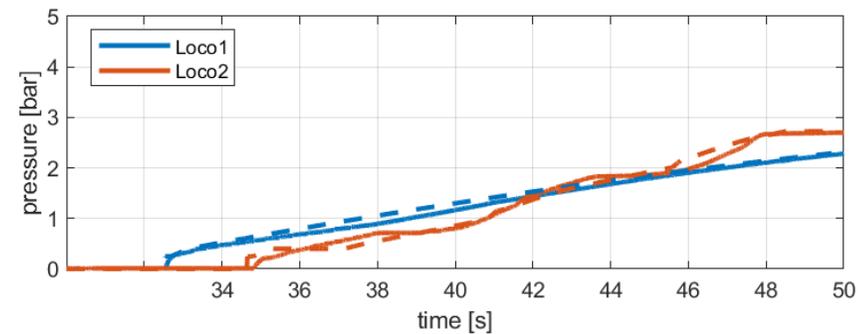
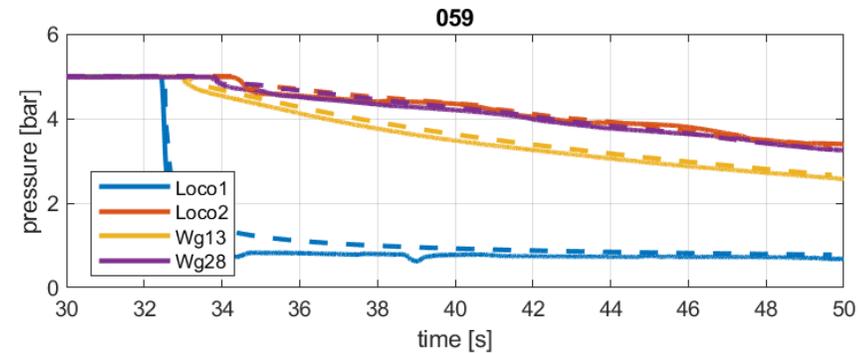
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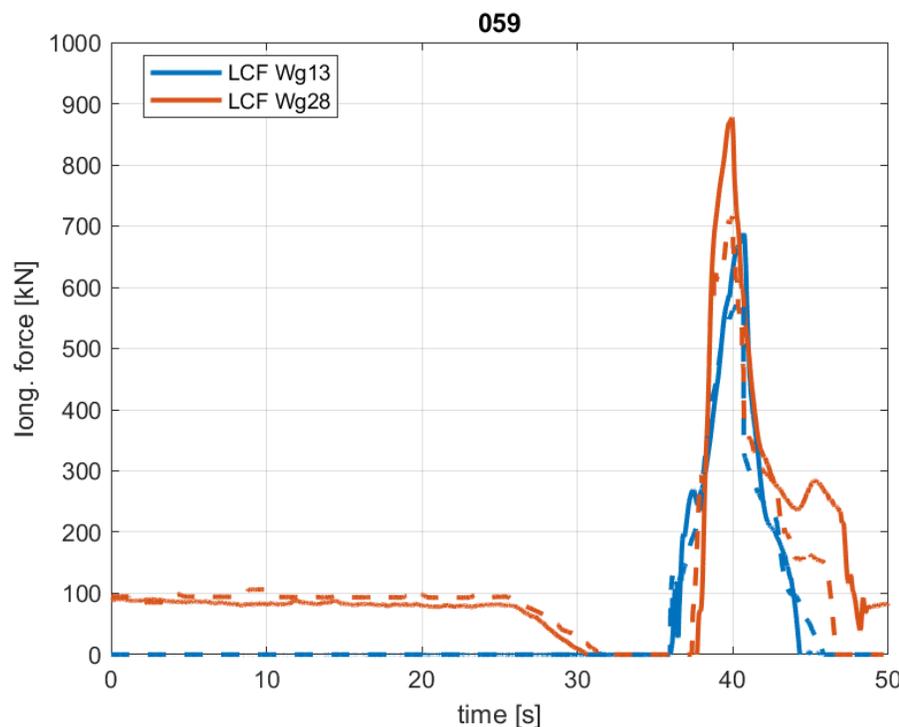




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Acceleration up to 30 km/h, loss of communication, reduction of traction from guided loco. Then, application of an emergency braking from the leading loco. Guided loco reduces the pressure in BP step-wise.



	Error [%]
Coupling 13	16.45
Coupling 28	16.86

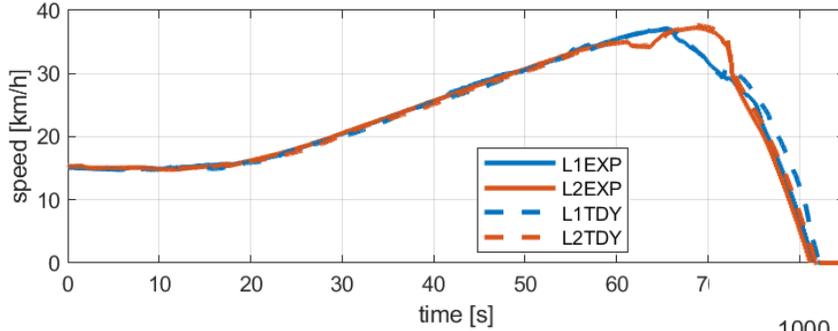
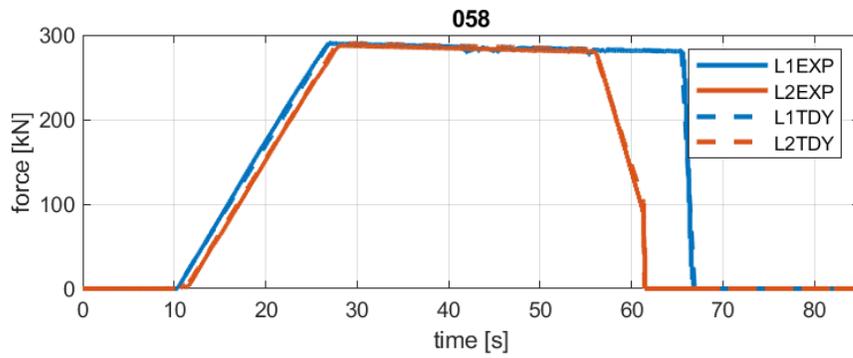
← Instantaneous forces



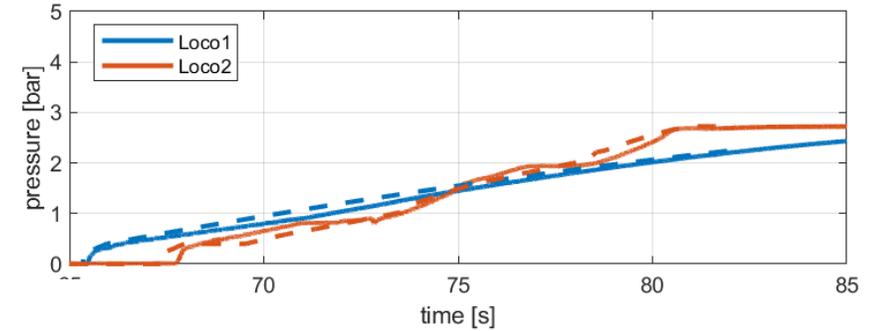
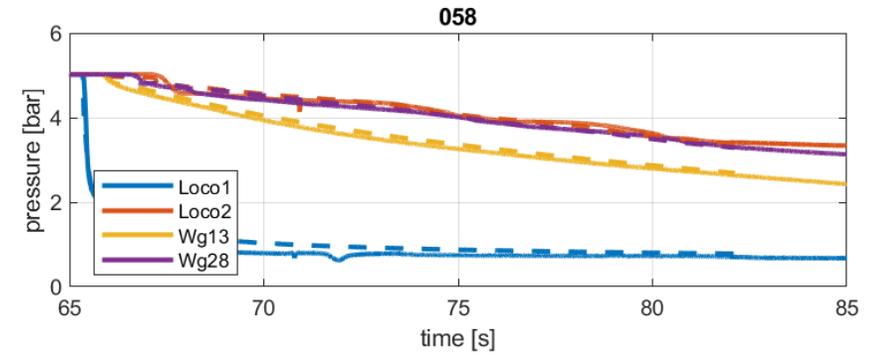
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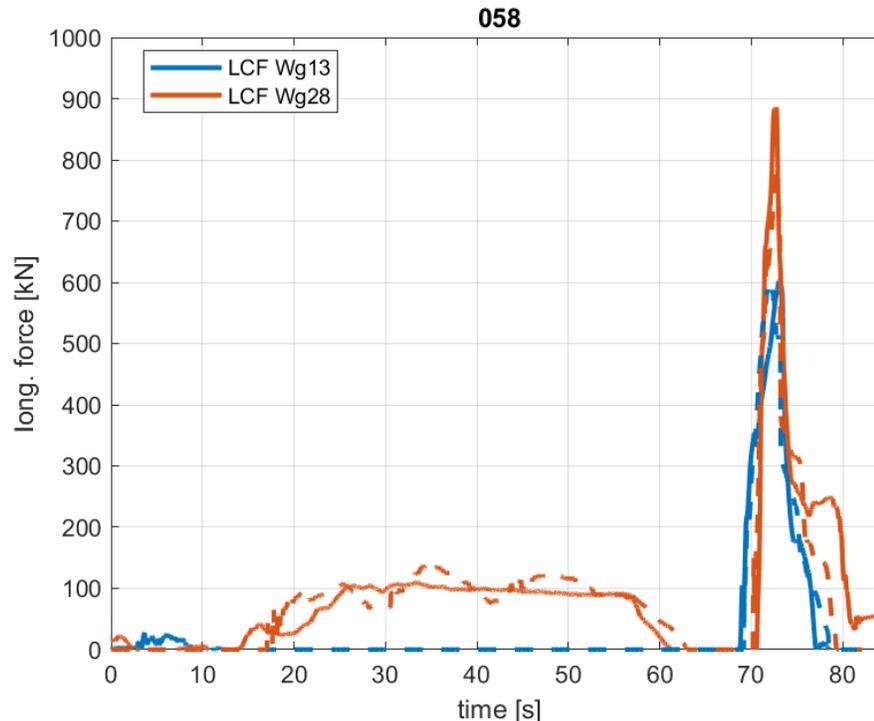




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Acceleration up to 30 km/h, loss of communication, reduction of traction from guided loco. Then, application of an emergency braking from the leading loco. Guided loco reduces the pressure in BP step-wise.



	Error [%]
Coupling 13	1.10
Coupling 28	10.68

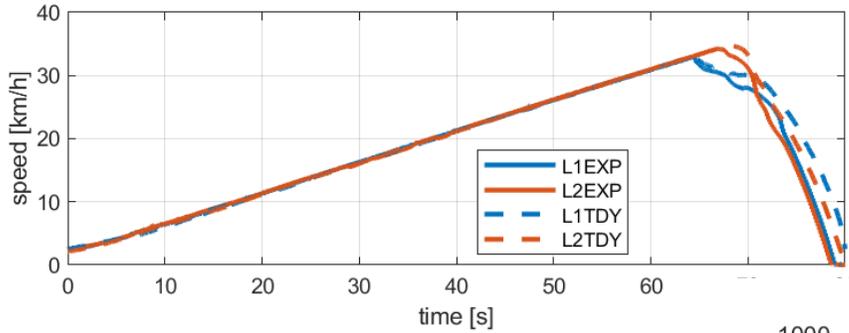
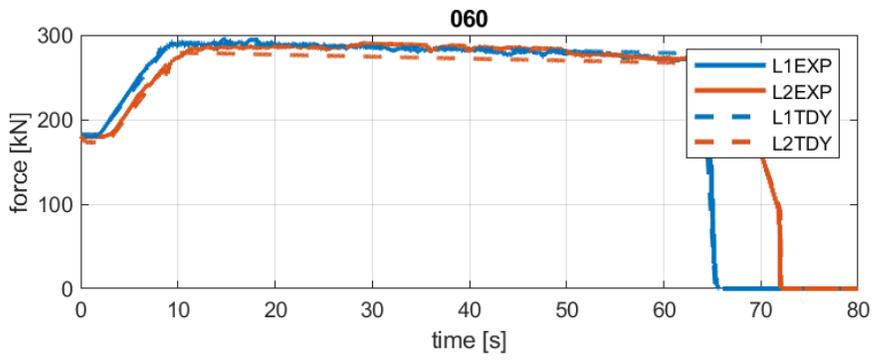
← Instantaneous forces



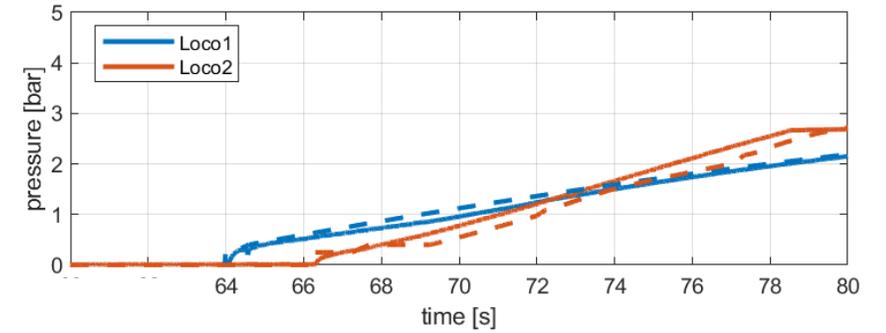
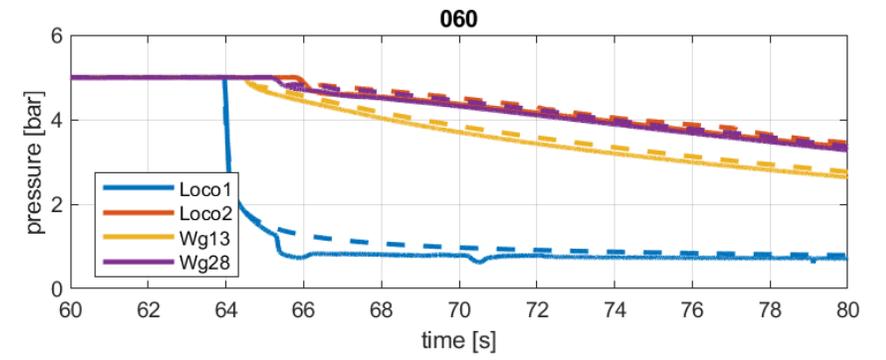
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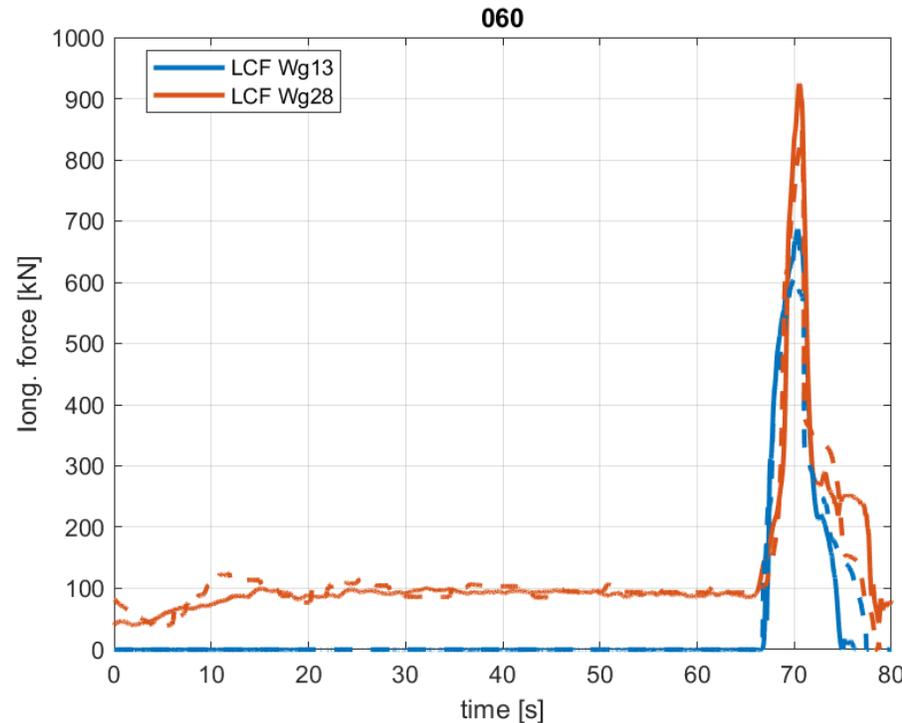




Solid line is used for measurements, dashed line for simulations.



Acceleration up to 30 km/h,
Emergency braking from the leading
loco and simultaneous DPS off.
Guided TU reduces the power and
when it is zero, it starts the step-wise
reduction of pressure.



	Error [%]
Coupling 13	10.94
Coupling 28	6.73

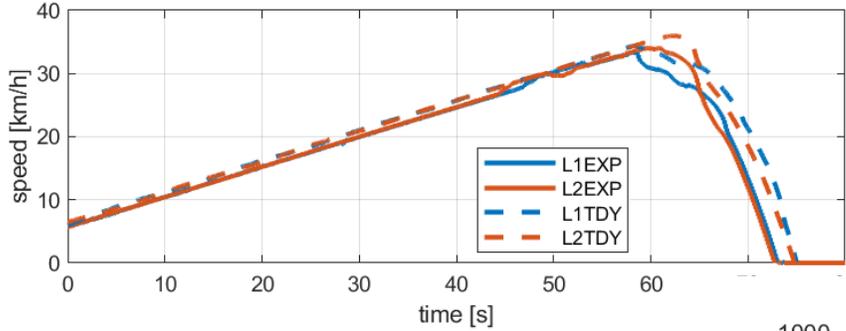
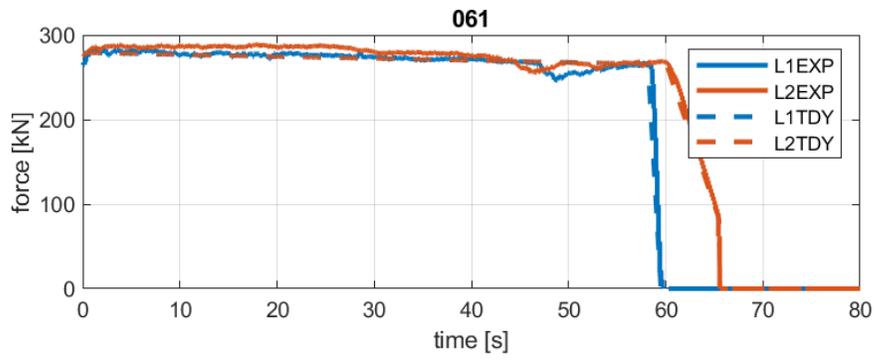
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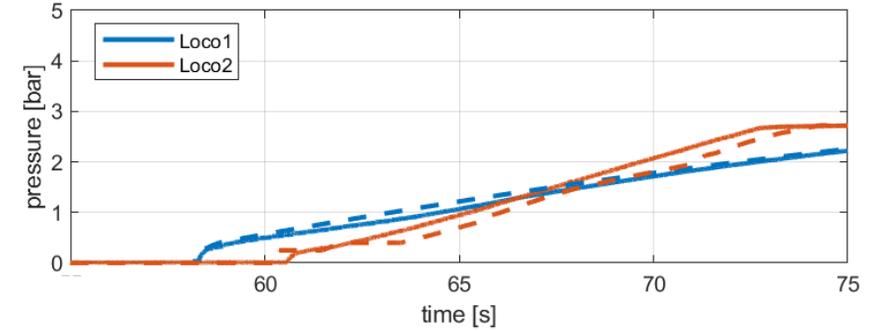
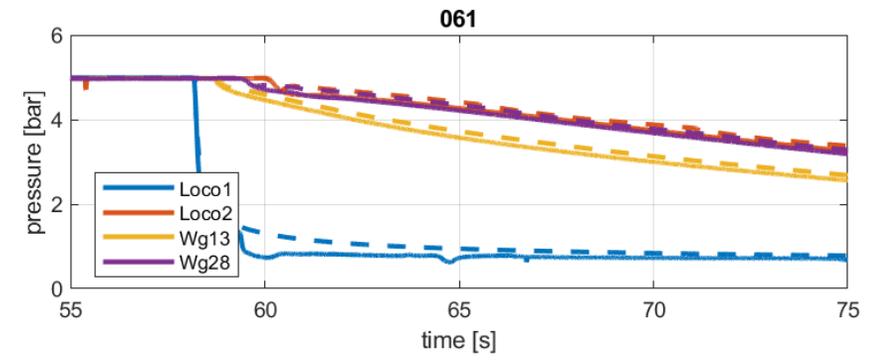
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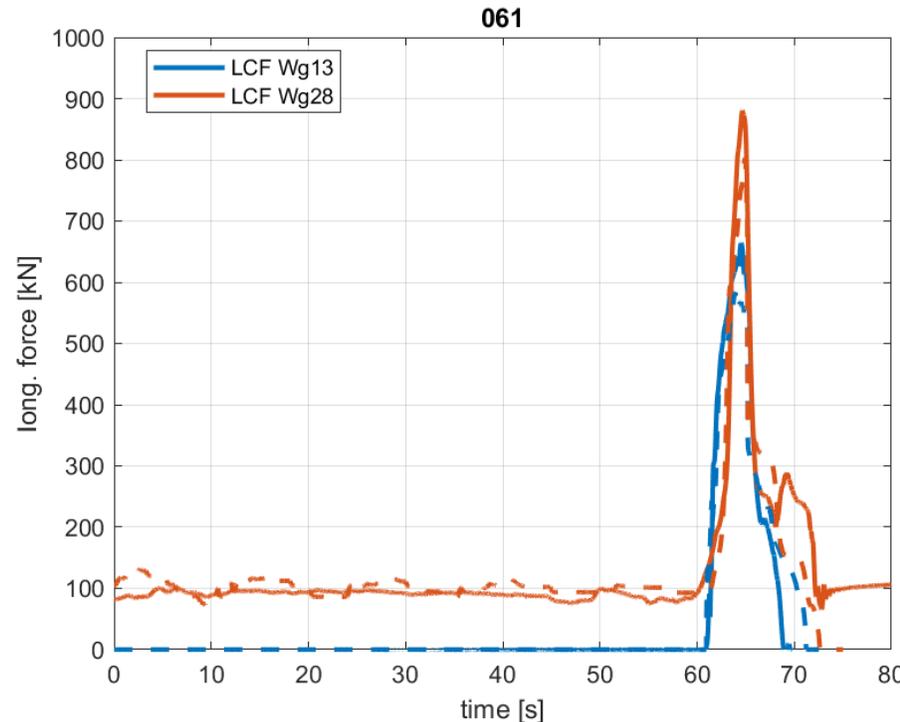


Solid line is used for measurements, dashed line for simulations.

	Error [%]
Maximum	16.9
Minimum	1.10
Average	10.2



Acceleration up to 30 km/h,
Emergency braking from the leading
loco and simultaneous DPS off.
Guided TU reduces the power and
when it is zero, it starts the step-wise
reduction of pressure.



	Error [%]
Coupling 13	11.57
Coupling 28	6.95

← Instantaneous forces



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Long homogeneous trains, running in G mode, with 1T-SW , of up to 7 T/m weight which length is up to 960 m with one locomotive at each end weighing 100T each and 20 m length each to add (BR187)

Nominal mode, LL shoes for all wagons

Maximum length 1200M



Mass T	2500/5500 Bk G	4000/4500 Bk G	4250/4750 BK G	5000/5500 BK G	5250/5750 BK G	6250/6750 BK G	7750/8250 BK G
Length M	GSM-R	GSM-R	GSM-R	GSM-R	GSM-R	GSM-R	GSMR
0/740	Fig.30						
700/740		S25	Fig. 32				
800/840				S29	Fig.32		
940/980						Fig.32	
1140/1180							S46

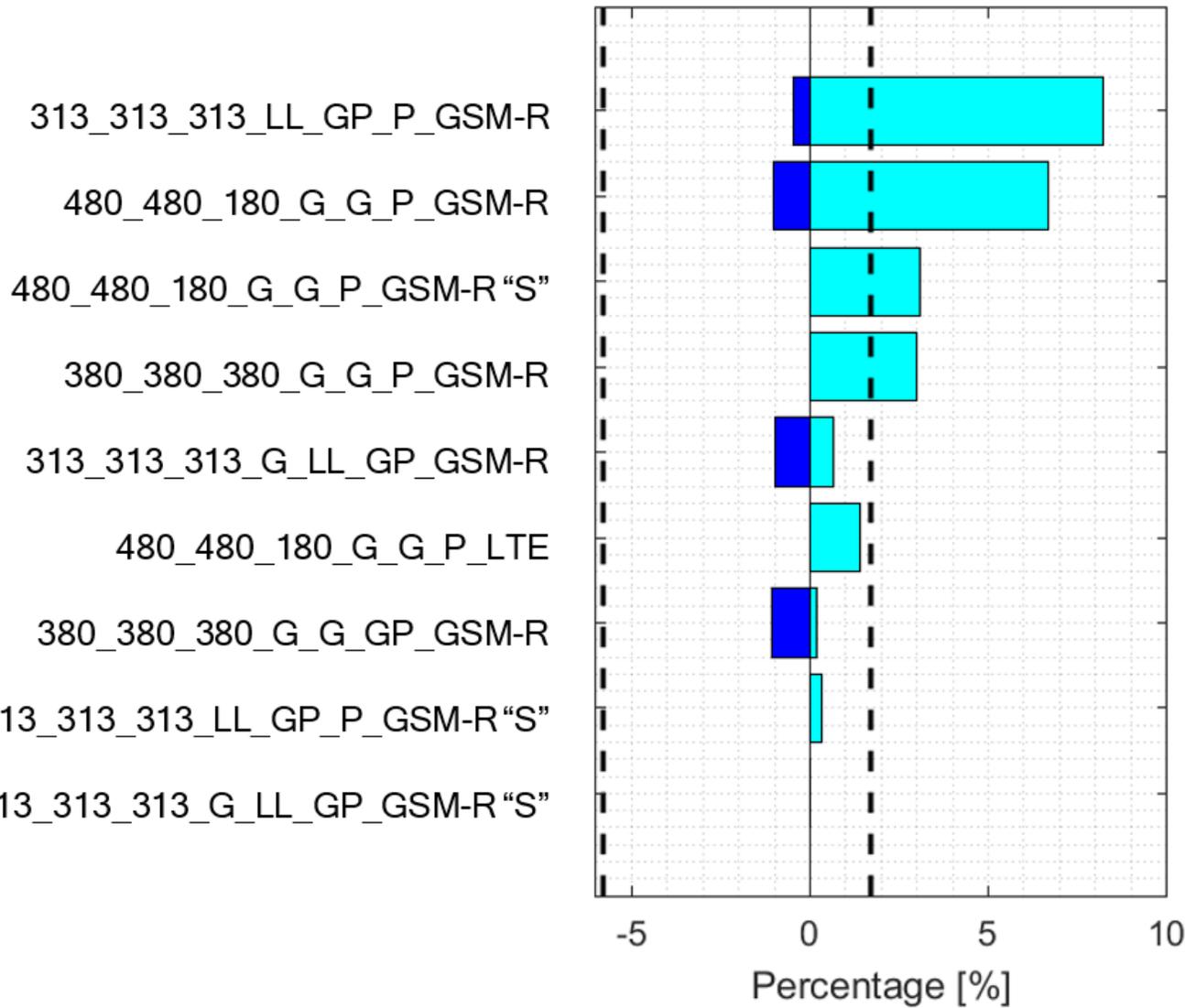
Coupled trains of combined transport with 2TUs 100km/h homogeneous wagons flat with bogies 2.6T/m average load but random loading or heavy ore homogeneous trains coupled with container trains behind

Nominal mode LL shoes for all wagons



1 st Train		400M		450M		500M				540M		580M	680M		700M	720M					
Radio Link		GSM-R		GSM-R		GSM-R			LTE	GSM-R	LTE	GSM-R	GRM-R		GSM-R	GSM-R				LTE	
2 nd Train		1200-1600T	1600-2500T	1200-1600T	1600-2500T	1200-1600T	1600-2500T	2500-3000T	2750-3250T	1200-1600T	1600-2500T	1600-2500T	1600-2500T	800-1200T	3500-4000T	3500-4000T	3500-4000T	800-1200T	1200-1600T	1600-2500T	1600-2500T
200M	0-800T					Fig.33	Fig.33			Fig.33											
	800-1200T						Fig.33														
250M	0-800T			Fig.33	Fig.33											Fig.34	Fig.34				
	800-1200T				Fig.33																
300M	0-800T		Fig.33					Fig.34							Fig.34						
	800-1200T	Fig.33							Fig.34												
	1200-1600T	Fig.33											Fig.34								
380M	0-800T																				
	800-1200T												Fig.34								
420M	0-800T										Fig.34										
	800-1200T									Fig.34	Fig.34										
440M	0-800T																				
	800-1200T																		Fig.35	Fig.35	Fig.35
	1200-1600T																			Fig.35	Fig.35
480M	0-800T													Fig.35							

3T in T-EB and GSM-R or LTE radio



Sub-train hauled mass [ton]:

P = 0-800; GP=801-1200; LL=1201-1600; G=1601-2500

Radio: GSM-R or LTE

"S" means that the leading TU brakes with delay, resulting in an "almost" synchronous braking



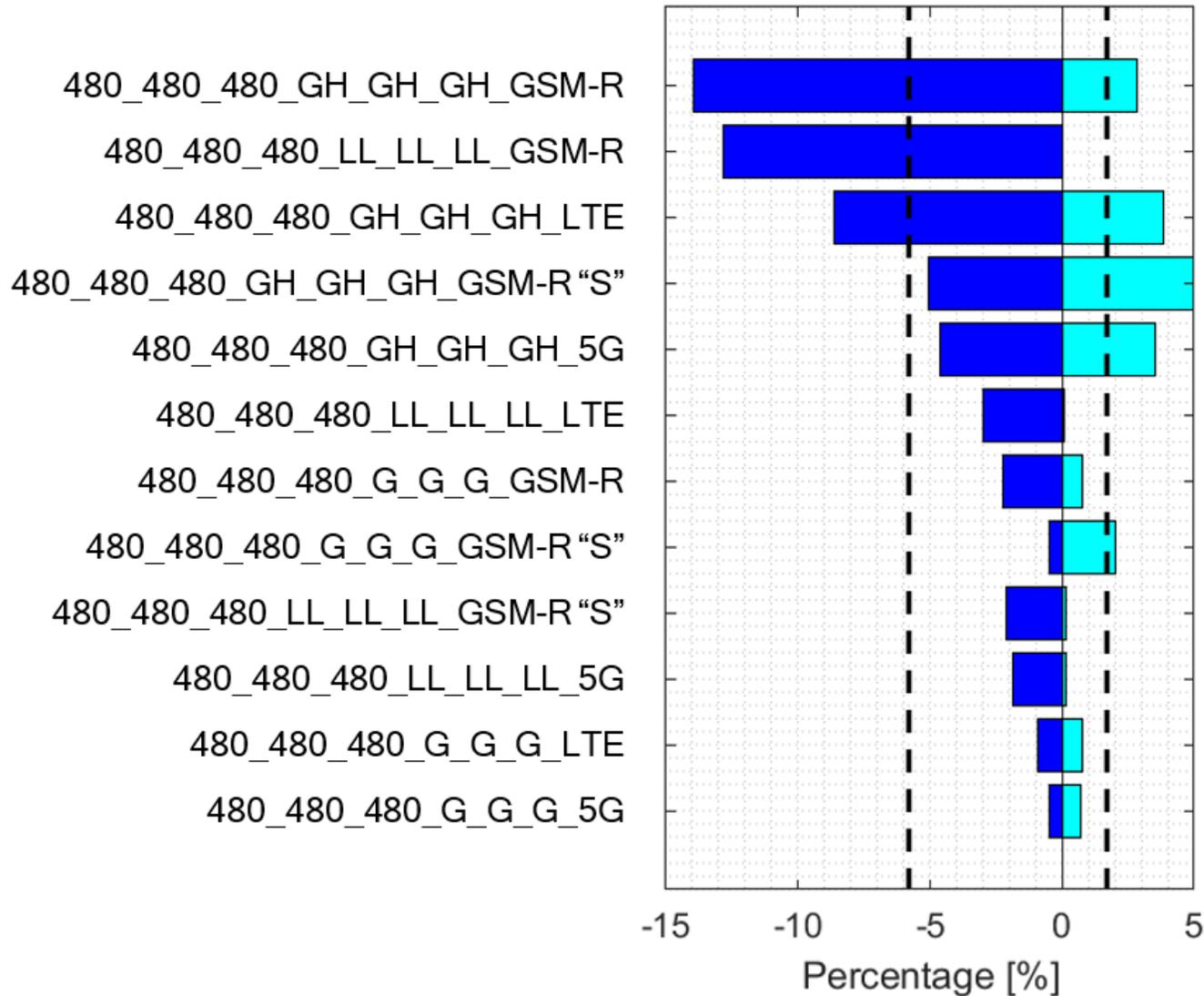
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3T and remote TU in T-EB, radio GSM-R, LTE and 5G



Sub-train hauled mass [ton]:

P = 0-800; GP=801-1200; LL=1201-1600; G=1601-2500;
 GH=2500-4000 (almost homogeneously loaded)
 Radio: GSM-R, LTE or 5G (towards next standard FRMCS)
 "S" means that the leading TU brakes with delay,
 resulting in an "almost" synchronous braking



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4T in T-EB, radio GSM-R, LTE, 5G and synchro braking

Coupling similar trains, in terms of length and mass is not the best option:

355_355_355_355_P_P_P_P

355_355_355_355_P_P_P_P

Sub-train hauled mass [ton]:

P = 0-800; GP=801-1200; LL=1201-1600; G=1601-2500;

GH=2500-4000 (almost homogeneously loaded)

Radio: GSM-R, LTE or 5G (towards next standard FRMCS)

"S" means that the leading TU brakes with delay, resulting in an "almost" synchronous braking

Coupling trains having decreasing length and mass is much better:

520_410_300_190_G_LL_GP_P

520_410_300_190_G_LL_GP_P

505_405_305_205_G_LL_GP_P_GSM-R

355_355_355_355_P_P_P_P_GSM-R

520_410_300_190_G_LL_GP_P_GSM-R

505_405_305_205_GP_GP_GP_GP_GSM-R

355_355_355_355_P_P_P_P_GSM-R "S"

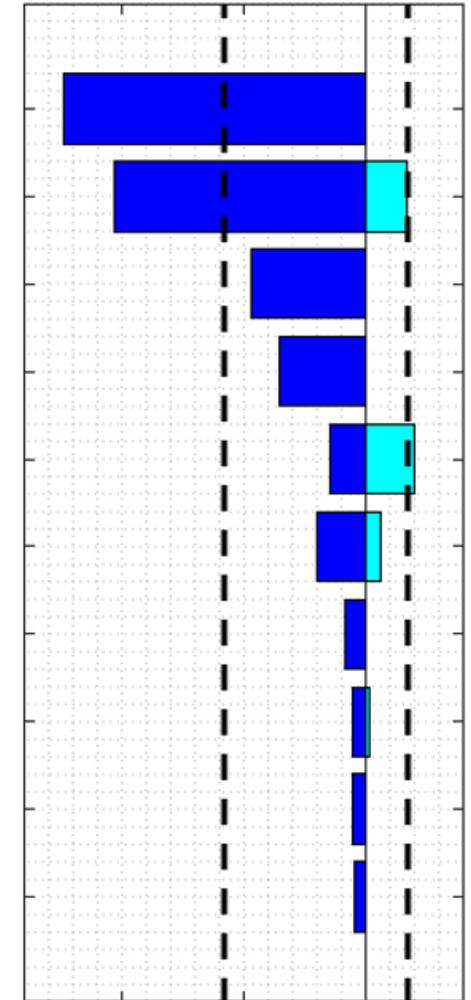
355_355_355_355_P_P_P_P_LTE

520_410_300_190_G_LL_GP_P_LTE

355_355_355_355_P_P_P_P_5G

520_410_300_190_G_LL_GP_P_GSM-R "S"

520_410_300_190_G_LL_GP_P_5G



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Simulation for FR8RAIL II Test Campaign (2021)

- ✓ Input: database of trains running from Kronach and Probstzella, where the track has gradients up to 27 ‰.
- ✓ Compare trains according to LTD, changing the technology: with or without DPS.



Reference train (REF) LWL



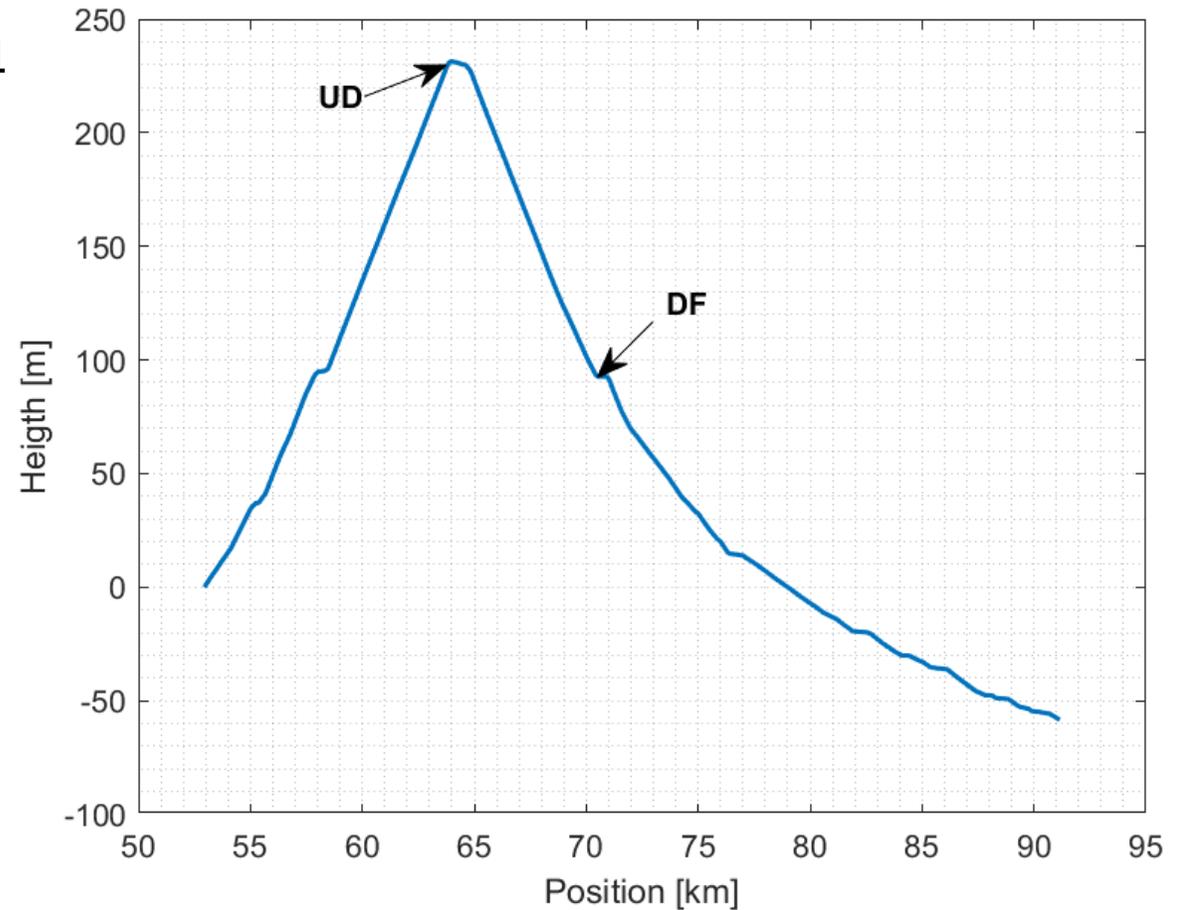
DPS train LWL



DPS train LWLW

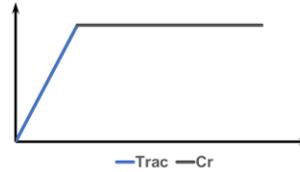


DPS train LWLWL

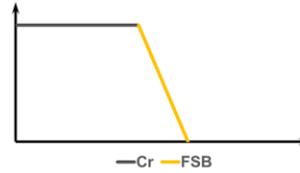


Simulation for FR8RAIL II Test Campaign (2021)

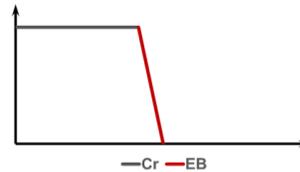
•1xxx Train acceleration and then coasting (cruising):



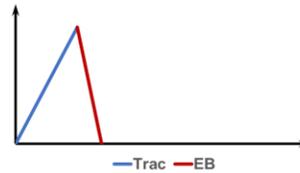
•2xxx Full-service braking from coasting (cruising):



•3xxx Emergency braking from coasting (cruising):



•4xxx Train acceleration followed by an EB:



Com. Loss!

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.



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.

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



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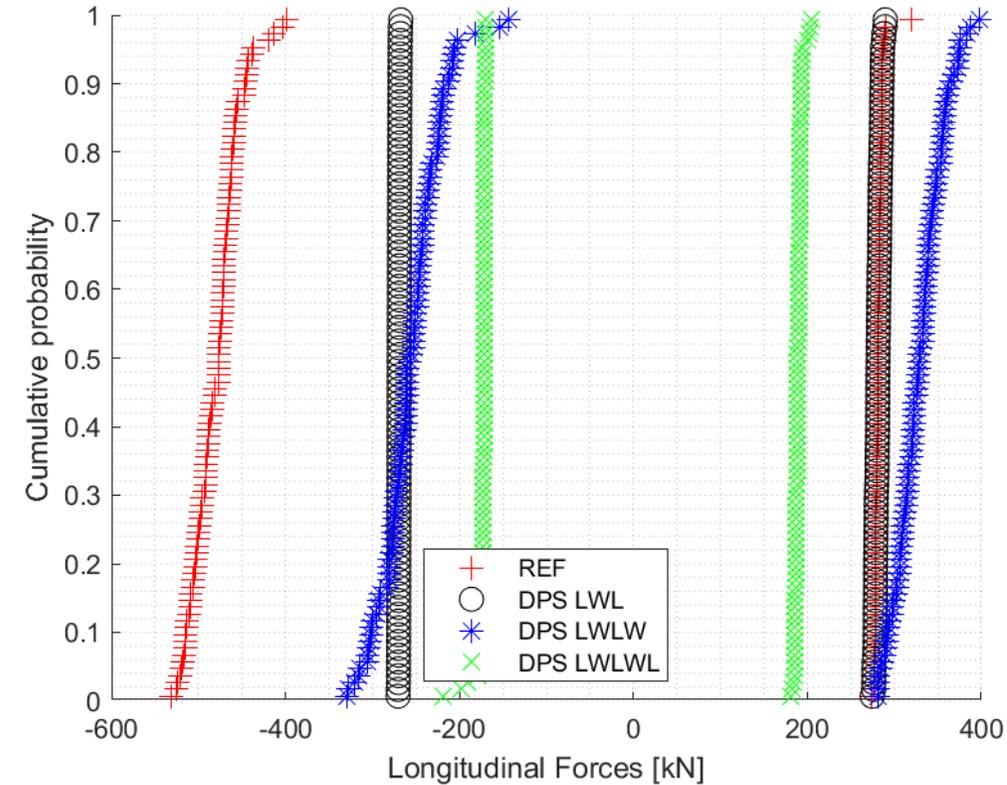
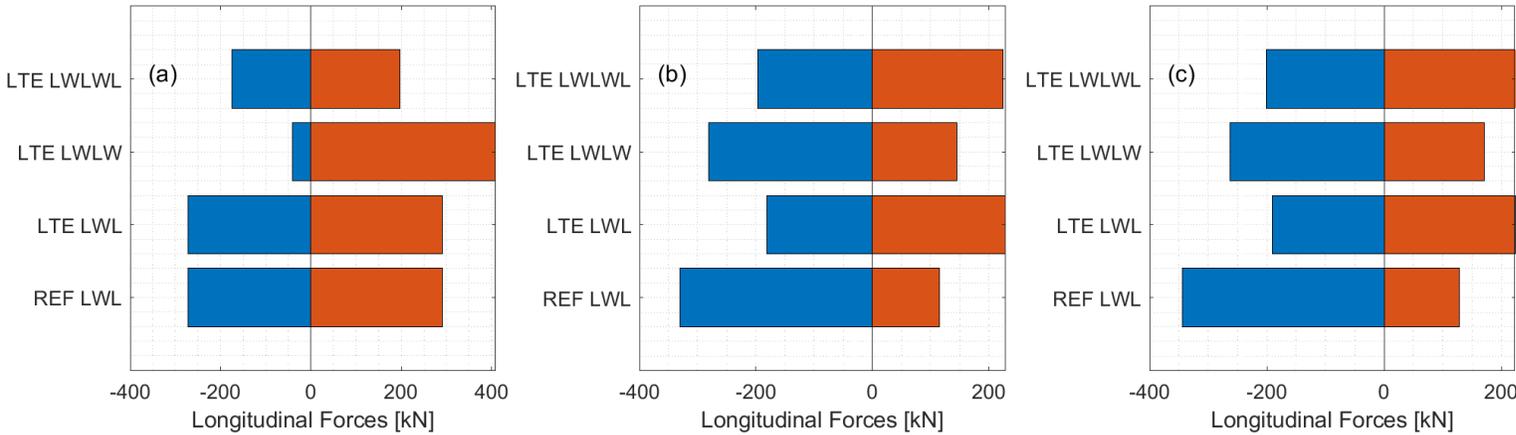


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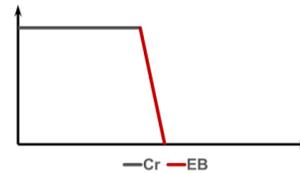
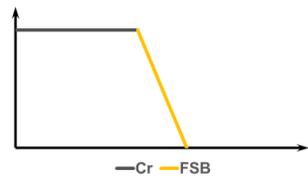
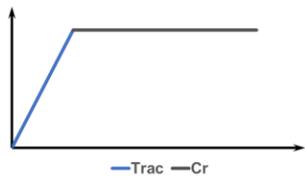


Simulation for FR8RAIL II Test Campaign (2021)

Nominal mode 



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



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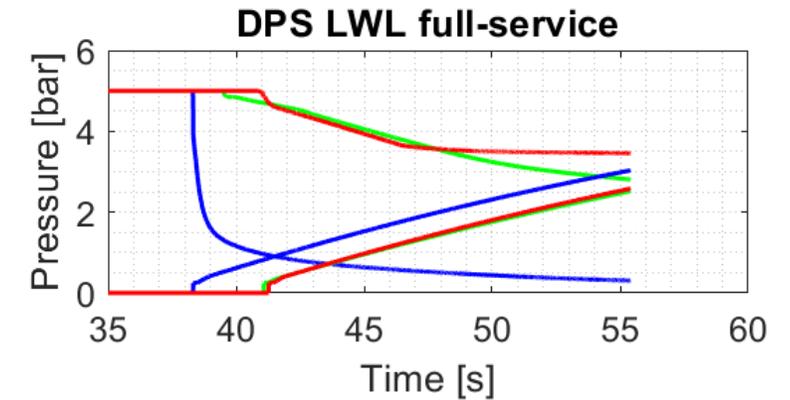
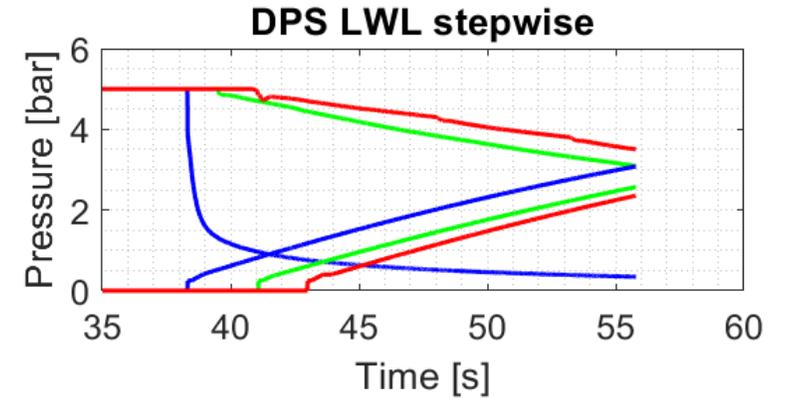
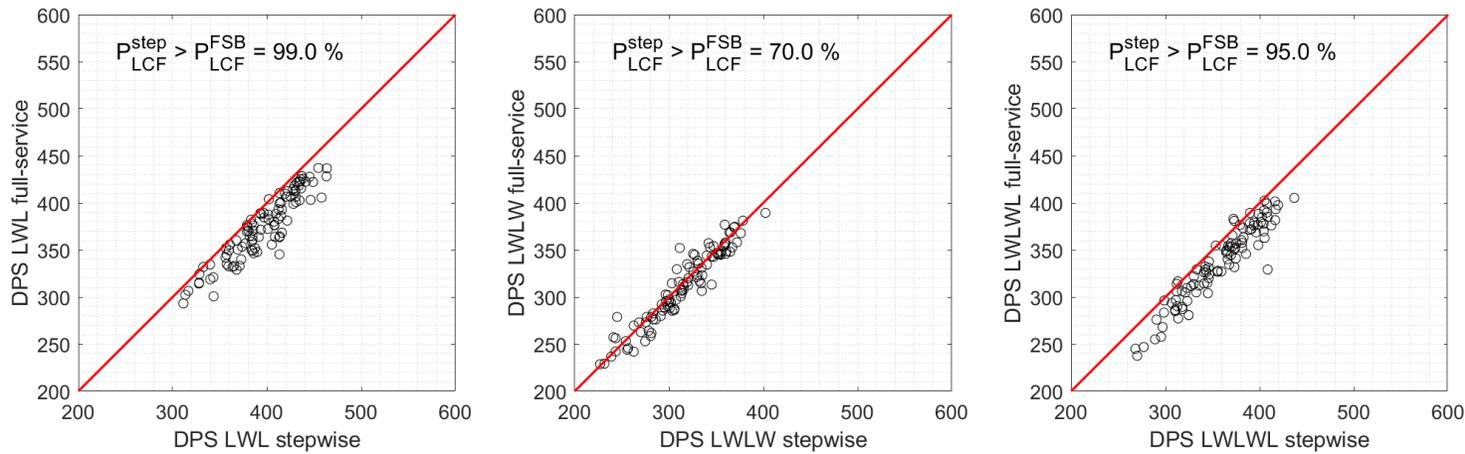
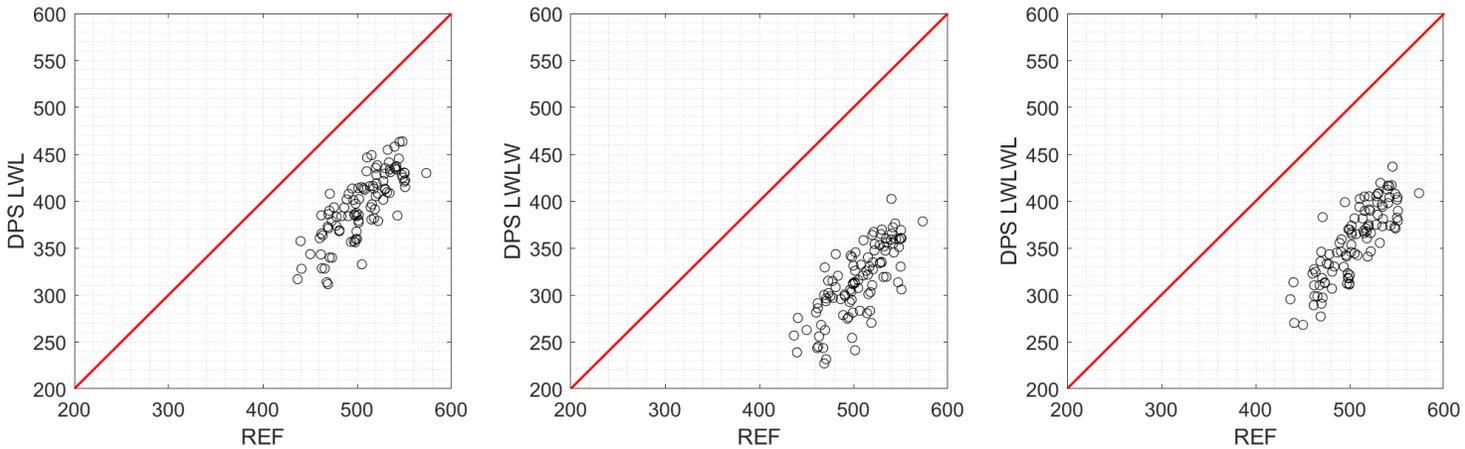
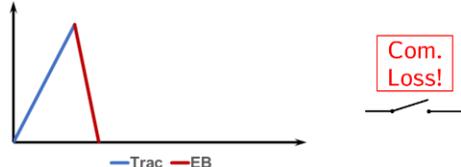


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“Degraded” mode



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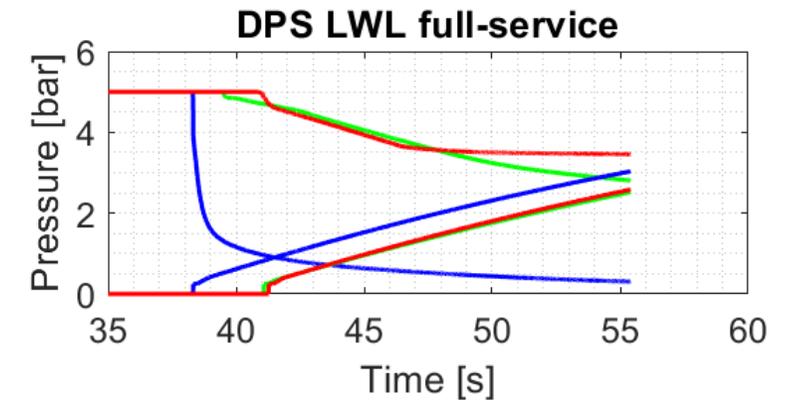
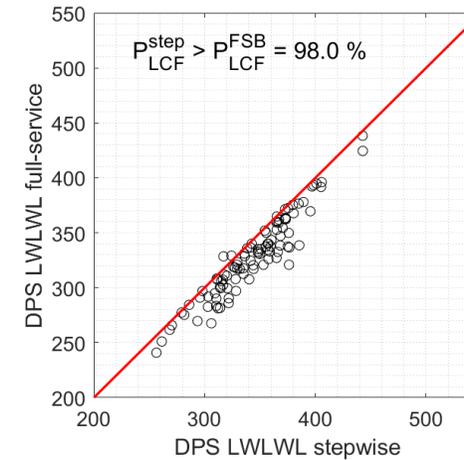
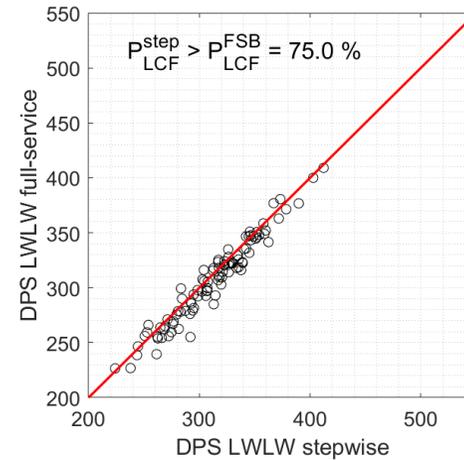
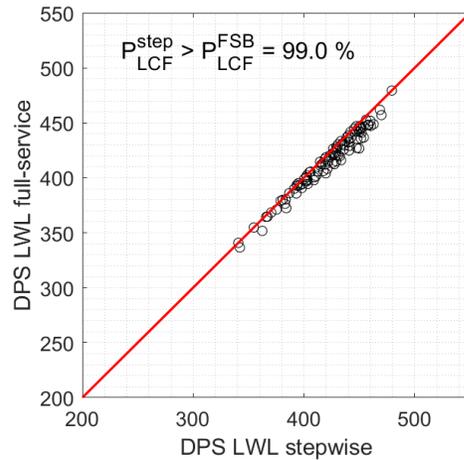
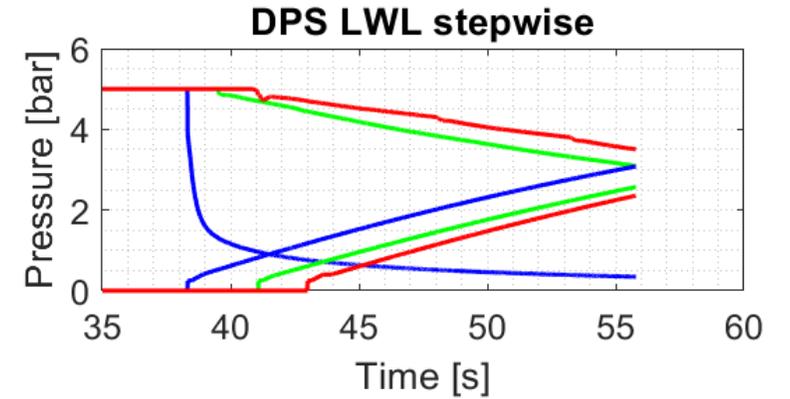
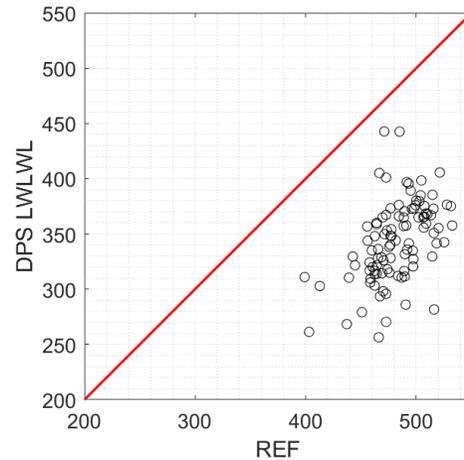
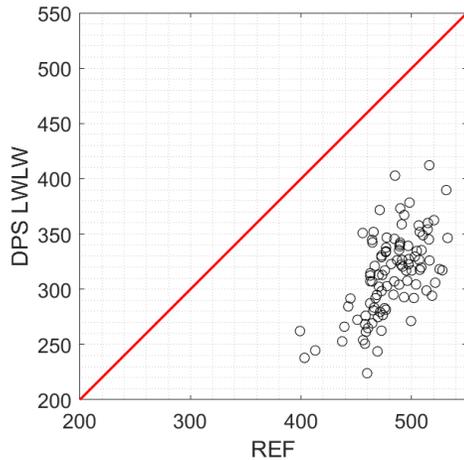
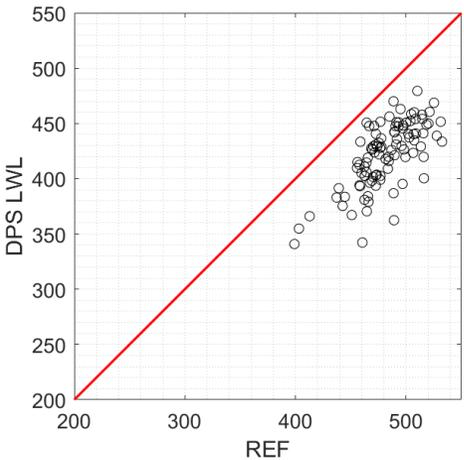
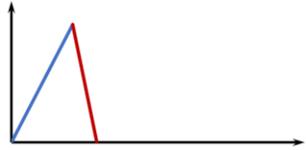


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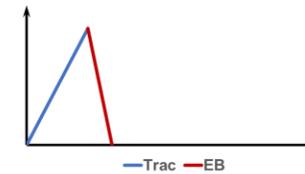
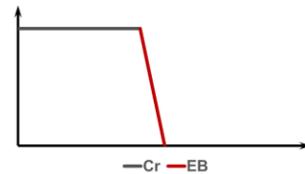
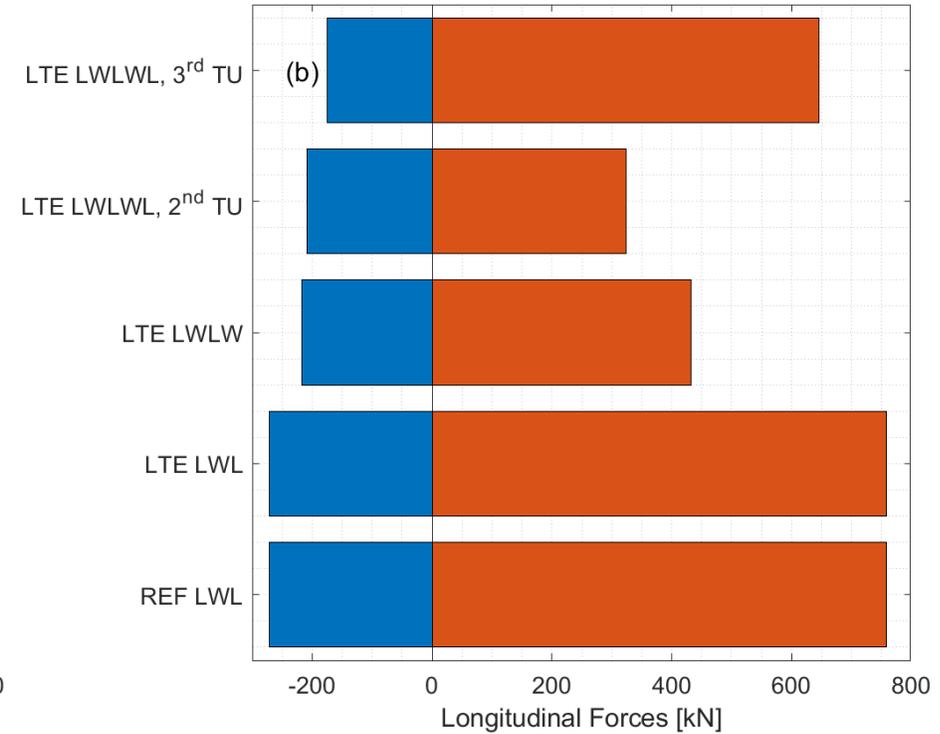
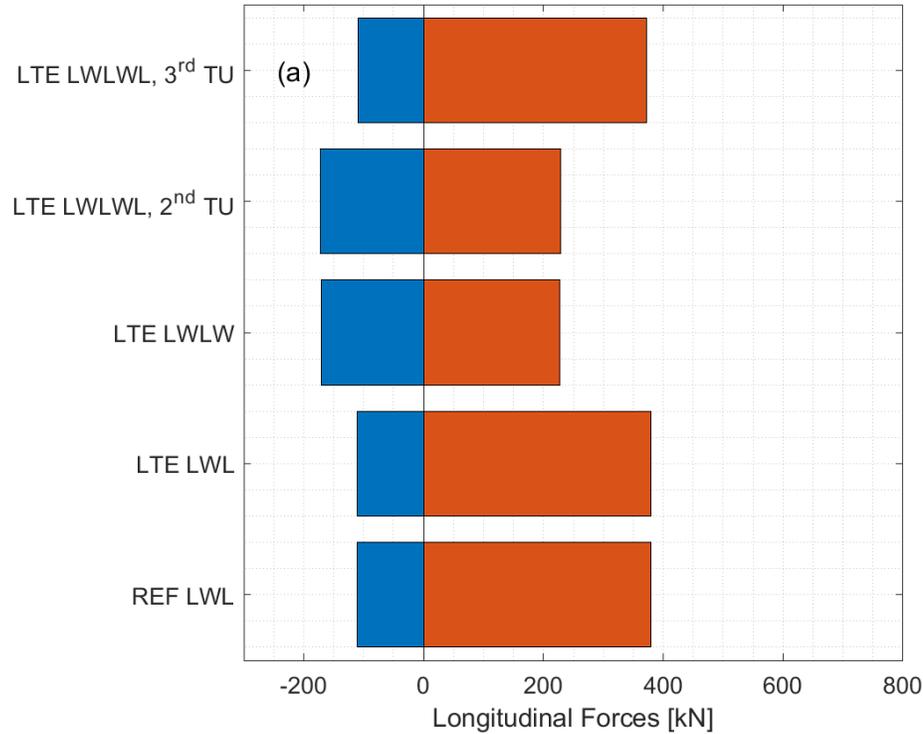
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"Not planned" Emergency Braking



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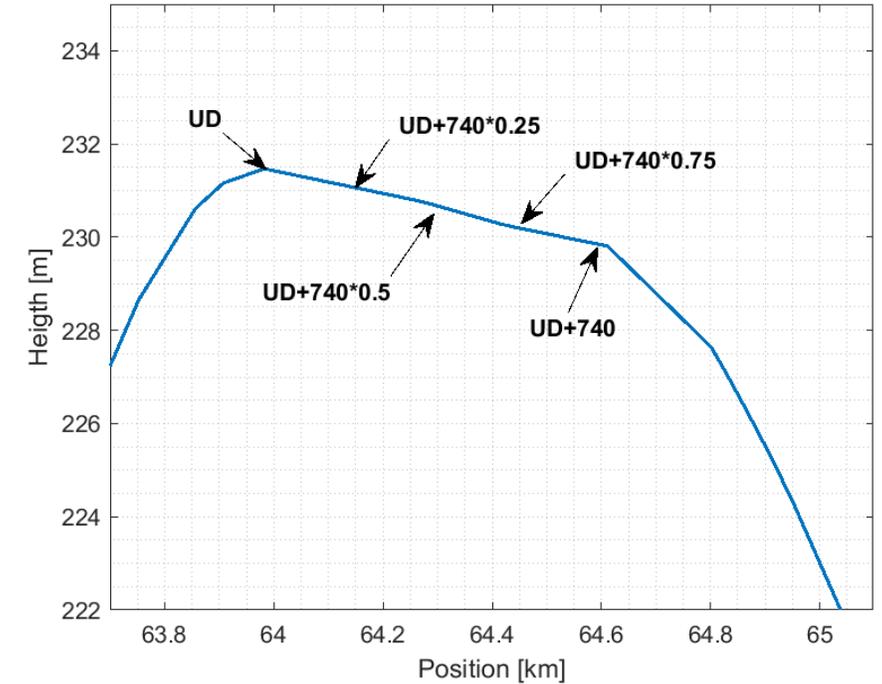
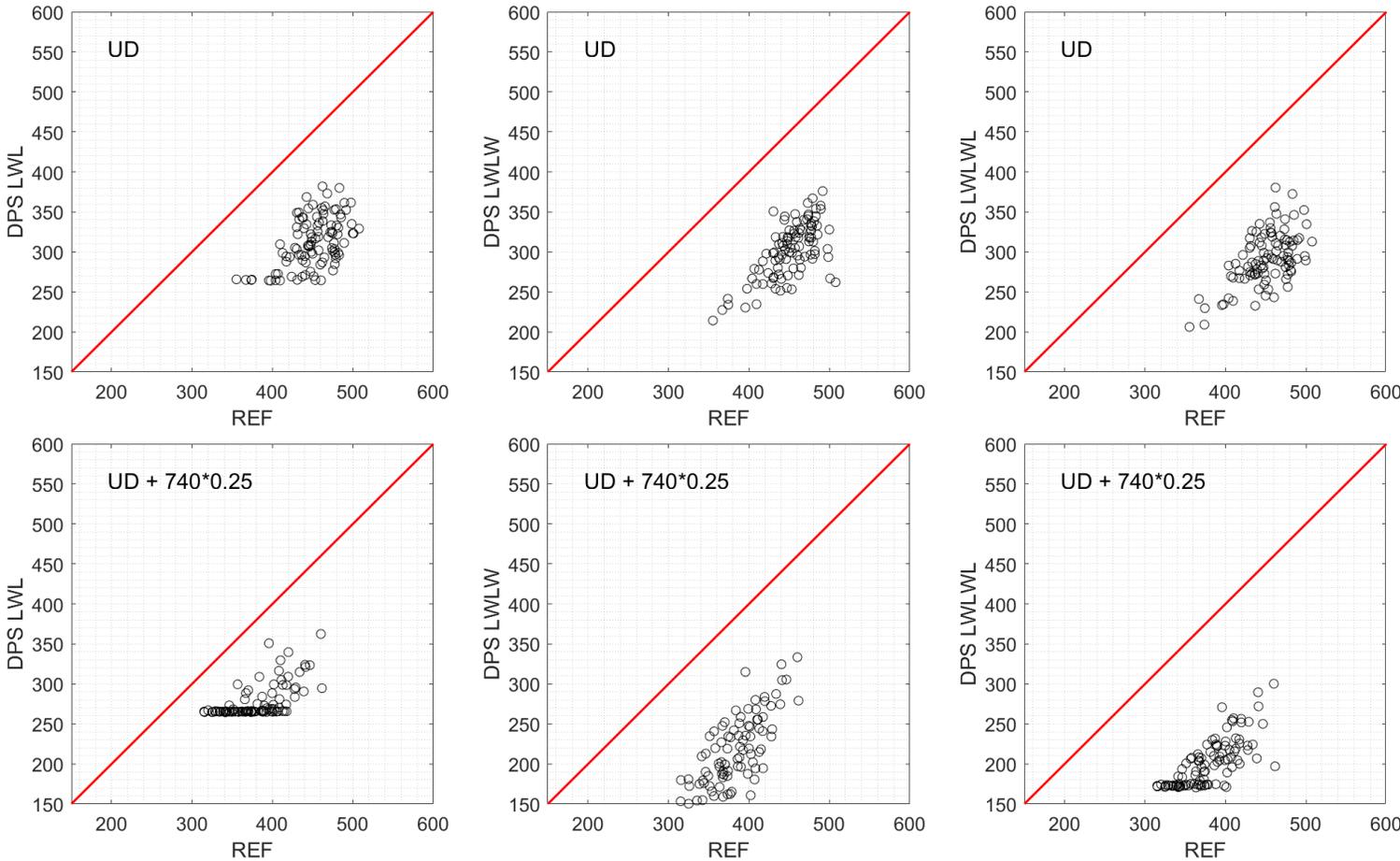
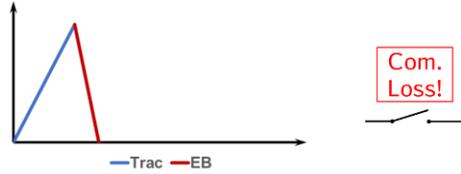


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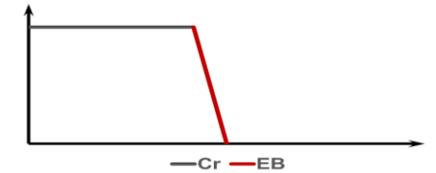
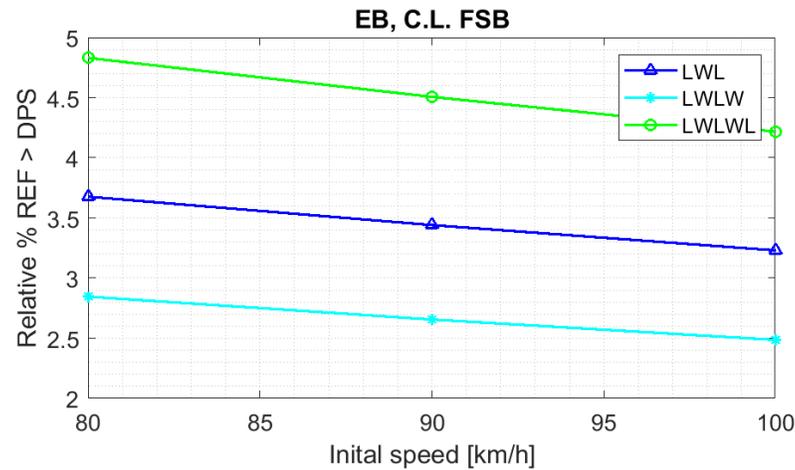
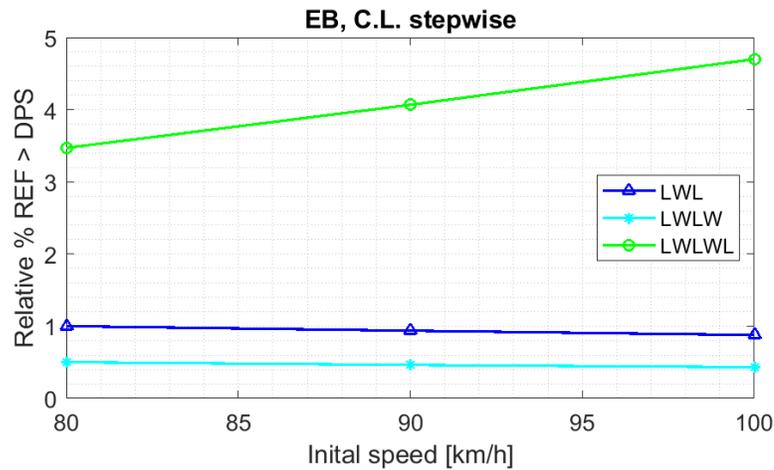
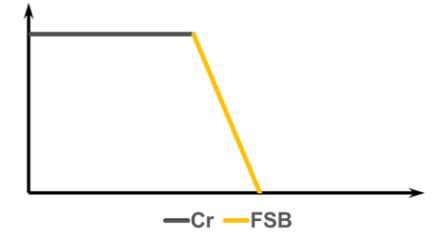
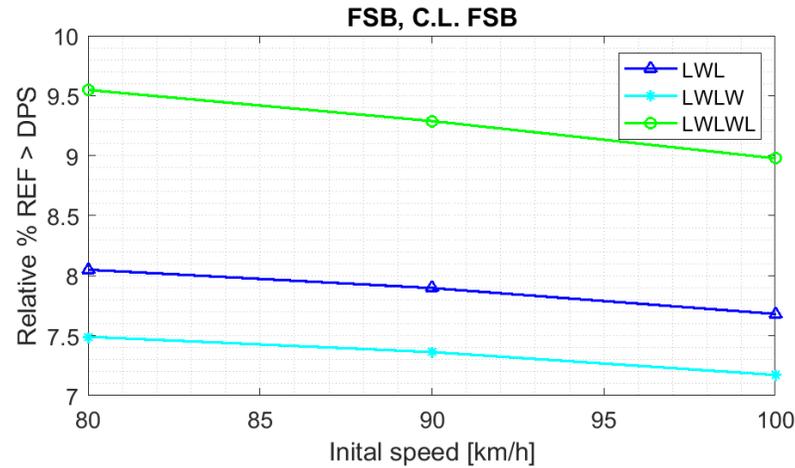
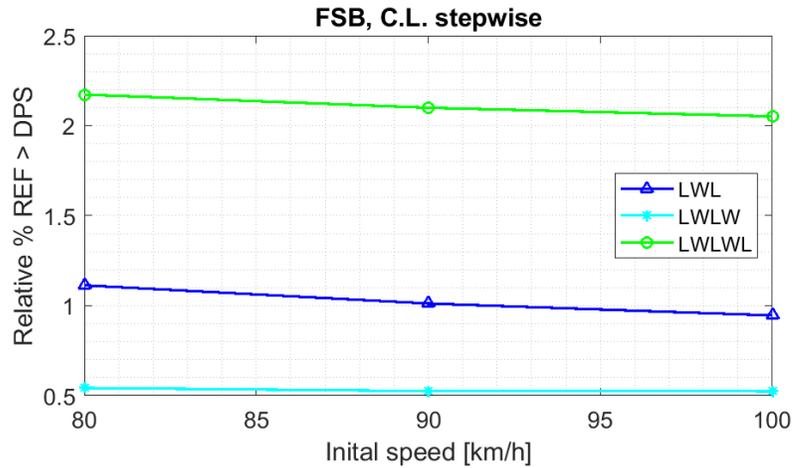
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“Degraded” mode



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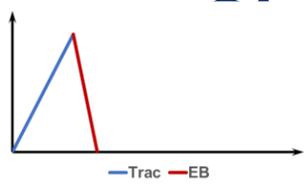


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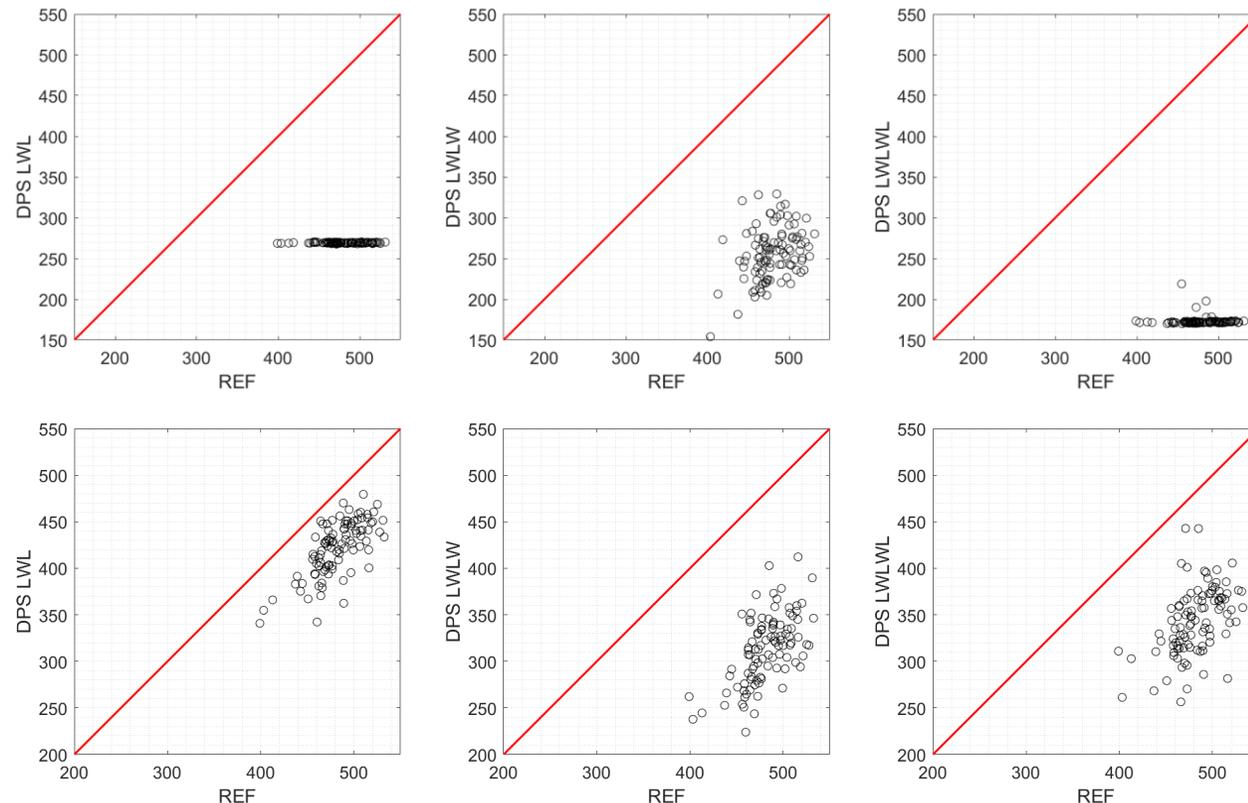
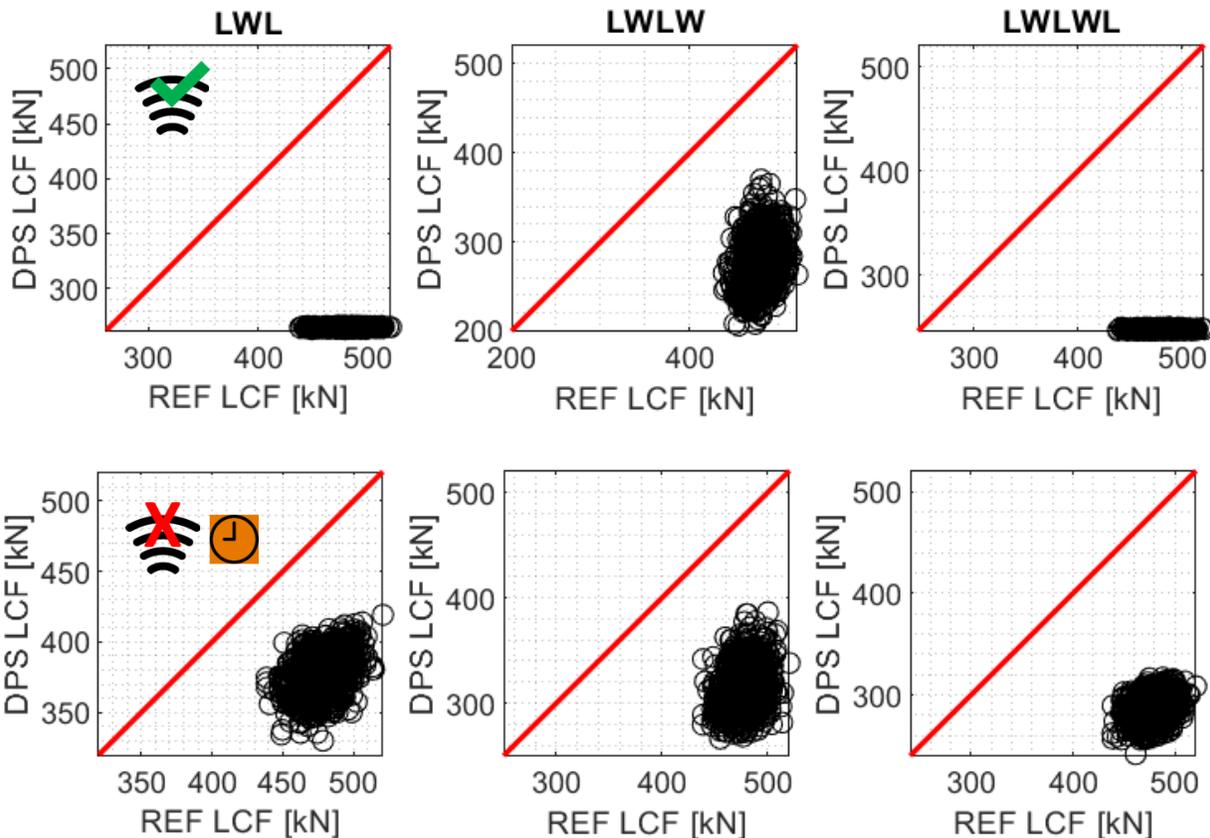
Simulation for FR8RAIL II Test Campaign (2021)

Other simulations



Trains in LL braking regime, with wagons permutation, to determine the exact trainset to be tested.

Trains in G braking regime, statistically generated from the database of trains running from Kronach and Probstzella



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Conclusions

- Sensitivity analysis has allowed to find the most relevant technical parameters for DPS trains
- Analyses with various types of consists have shown that there are several solutions suitable for the market (see next roadmap to implementation), according to the different “technology” implemented.
- A deeper analysis of trains suitable for the test campaign, have shown that DPS trains are always better than reference trains in nominal mode.
 - DPS trains are better than REF trains also in degraded mode and when this is not true the in-train forces are of no concern (i.e., below admissible values).
 - Other simulations on the specific train configuration to be used for the test campaign are confirming above conclusions.