# A statistical study on long freight trains equipped with radio communication within Shift2Rail

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# Introduction

- Marathon2Operation, a Shift2Rail Open Call Project for long trains equipped with radio communication.
- Main M2O objectives:
  - Integrate the radio solution within the existing Traction Unit for the test demonstrators.
  - Study the safety of these new trains at general level and with respect to the test demonstrators
  - Simulate the longitudinal train dynamics of different train consists, according to the hauled mass, the length, the number of TU employed and the radio technology.
  - Preliminary safety analysis and assessment.

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# 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

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# 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. | - Brake pipe diameter<br>- 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. | - Track characteristics<br>- 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

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# 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.

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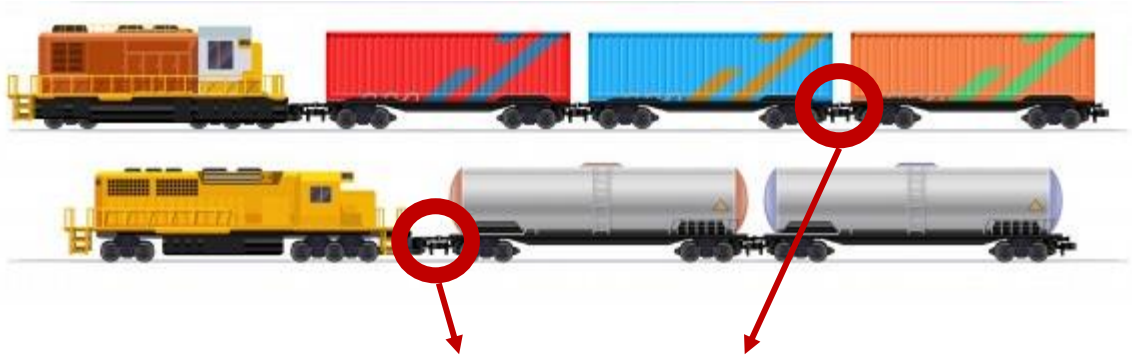
# TrainDy results extraction: the CDF

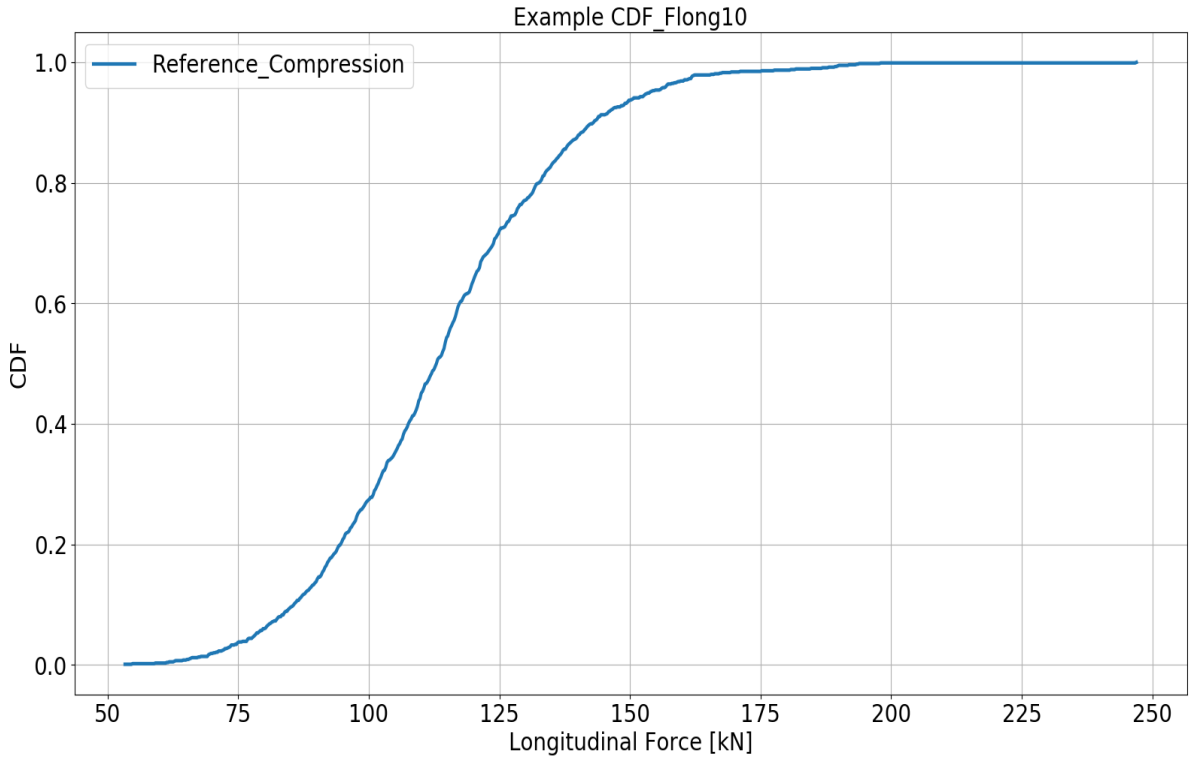
1000 TrainDy simulations
(one for each train in family)



Max Longitudinal force registered <u>among all train wagons and among all time-steps</u> for each train.

Both for traction and compression forces

Cumulative Distribution Function (CDF) of such forces.

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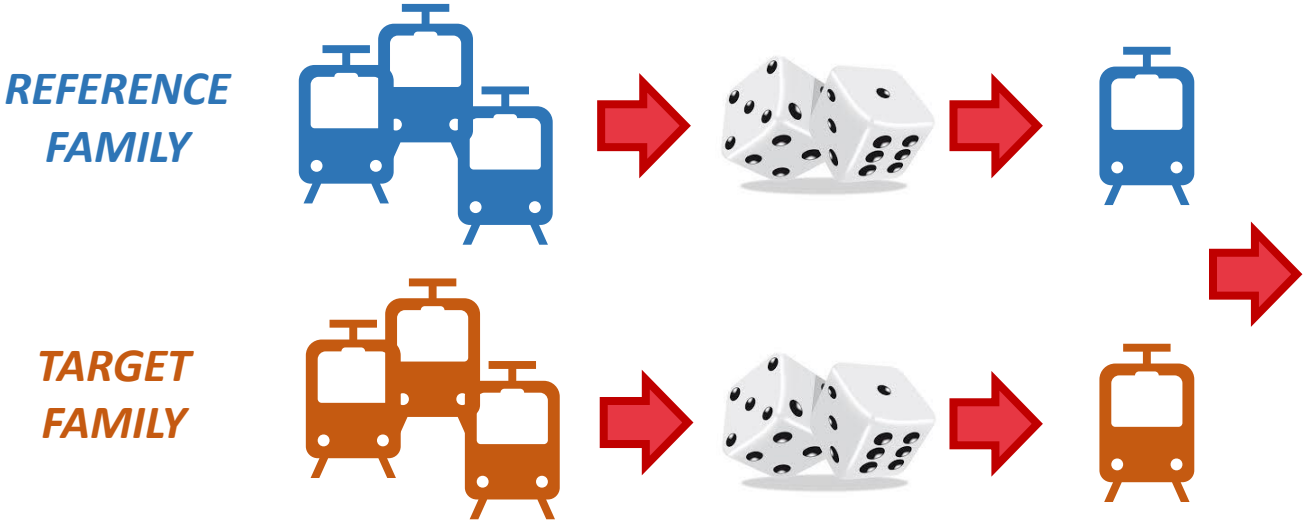
# Sensitivity metrics: the LFP

- Every sensitivity analysis requires one or more scalar output
- Ad hoc additional indicators have to be developed to deal with CDFs output
- Different indicators can lead to different importance rankings and deliver different kind of information about the results




*The Lower Force Probability* (**LFP**) is defined as the probability that the target train would present lower longitudinal forces than the reference one.

**N.B.** The LFP of Vs will be ALWAYS equal to 50%

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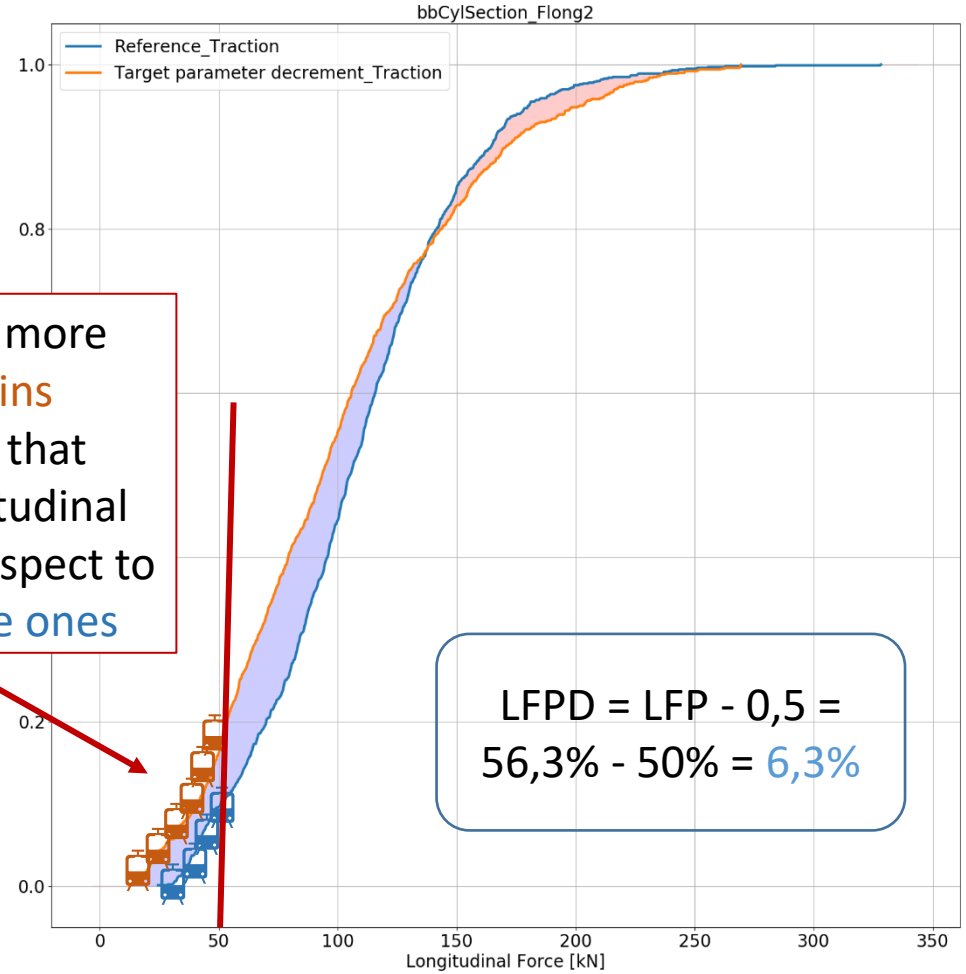
# Sensitivity metrics: the LFPD

*The Lower Force Probability Differential* (**LFPD**) is defined as:

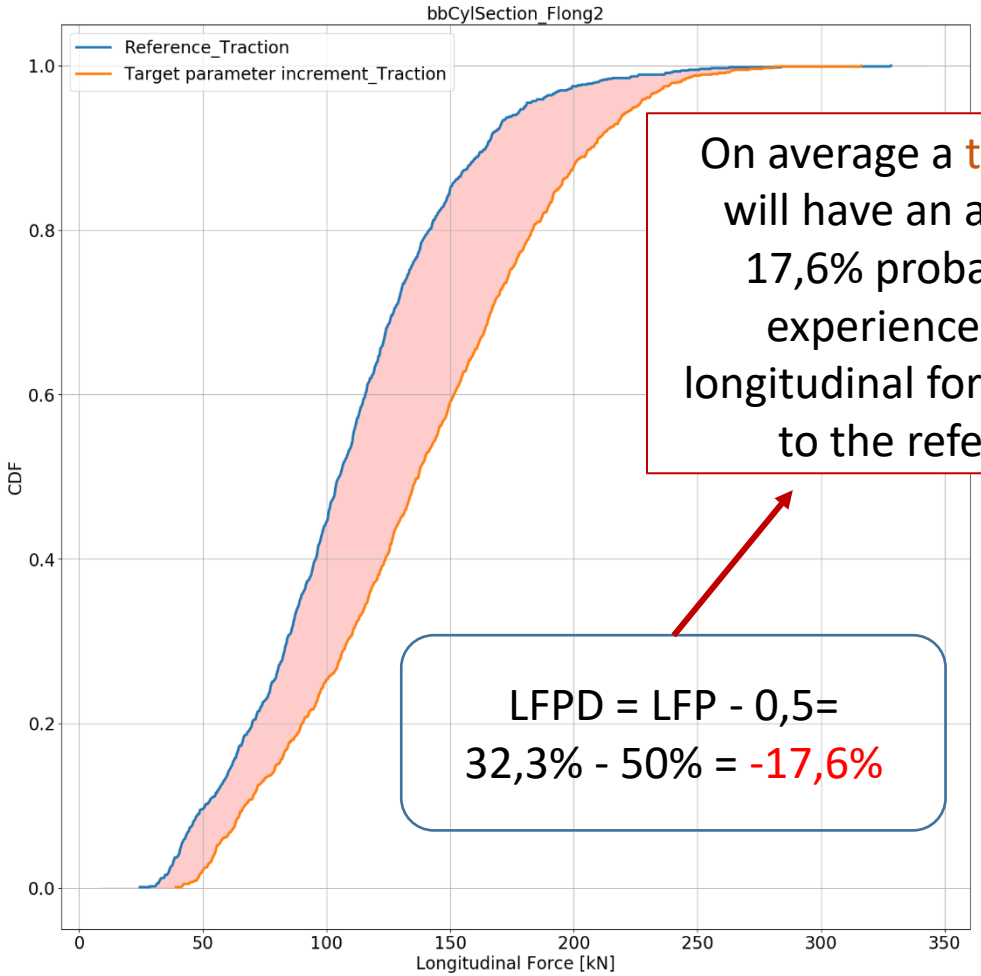
The LFP of Vs will be ALWAYS equal to 50%

$$\mathrm{LFPD} = \mathrm{LFP}_{TvsR} - \mathrm{LFP}_{RvsR} = \mathrm{LFP}_{TvsR} - 0{,}5$$




On average, more target trains experience that specific longitudinal force or less respect to the reference ones

LFPD = LFP - 0,5 =
56,3% - 50% = 6,3%




On average a target train will have an additional 17,6% probability to experience higher longitudinal forces respect to the reference.

LFPD = LFP - 0,5=
32,3% - 50% = -17,6%

# Methodology

- Three reference families considered: 400LL 300GP, N202 400LL 300GP and 4GP
- Realistic technical uncertainties (sourced from literature/experts).
- "Finite Change" approach:

Between 1% and 10% (most of the parameters)

$$\boldsymbol{x} = (x_1, \dots, x_i, \dots, x_n) \qquad \Delta\boldsymbol{x}^+ = (\Delta x_1^+, \dots, \Delta x_i^+, \dots, \Delta x_n^+) \qquad \boxed{\Delta x_i = \pm 3\sigma_i}$$

**GENERAL:**

$$D_i^1 = G(x_1, \dots, x_i + \Delta x_i, \dots, x_n) - \mathrm{G}(\boldsymbol{x})$$

$$D_i^{tot} = \mathrm{G}(\boldsymbol{x} + \Delta\boldsymbol{x}) - G(x_1 + \Delta x_1, \dots, x_i, \dots, x_n + \Delta x_n)$$

**SPECIFIC:**

$$D_i^1 = \mathrm{LFP}_i - 0{,}5 = \mathrm{LFPD}$$

$$D_i^{tot} = \mathrm{LFPD}_{\mathrm{all}} - \mathrm{LFPD}_{\mathrm{all\_but\_i}}$$

$$(4 \cdot 19 \text{ parameters} + 2) \cdot (3 \text{ families} \cdot 1000 \text{ trains}) \approx 234k$$

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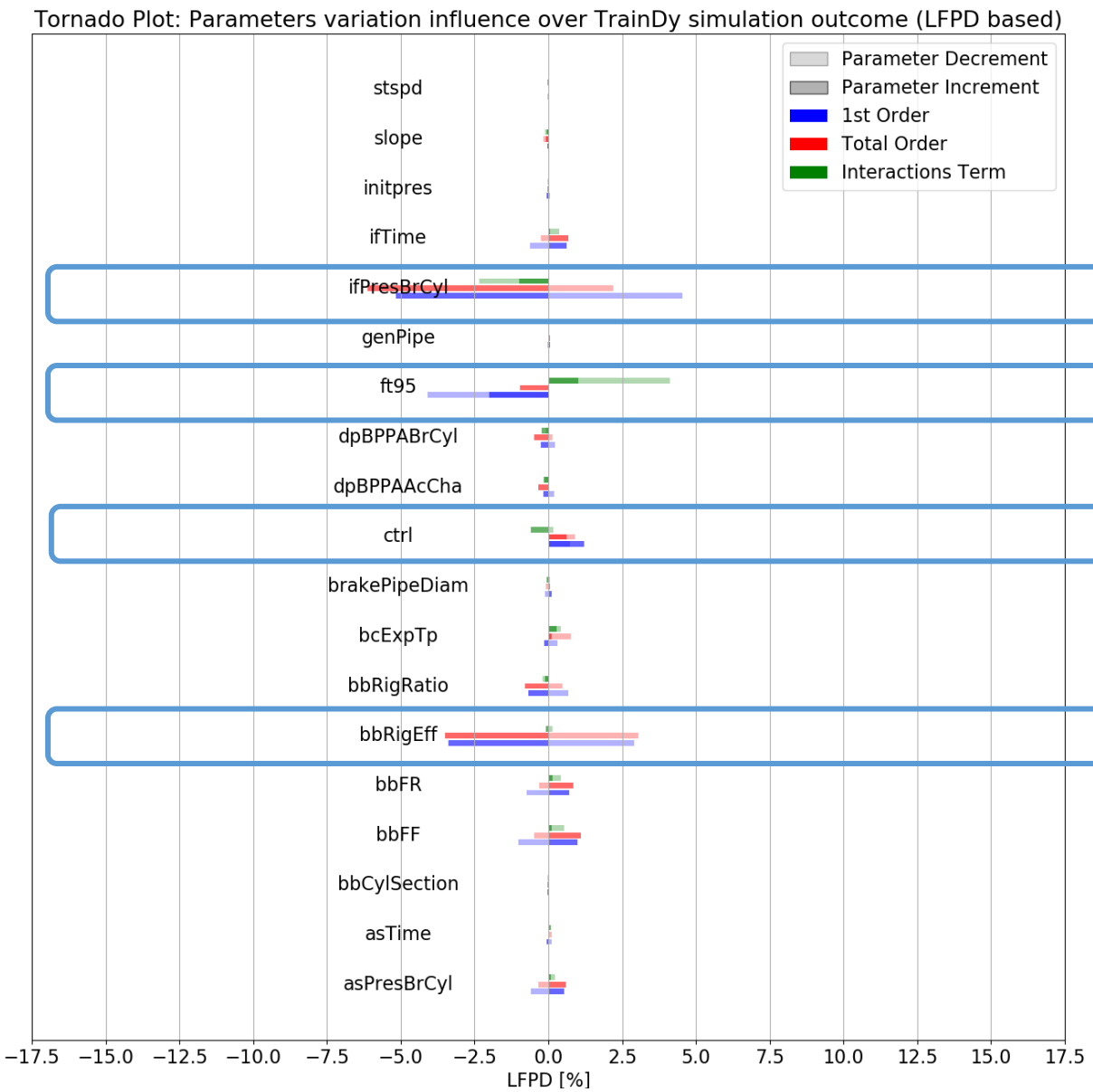
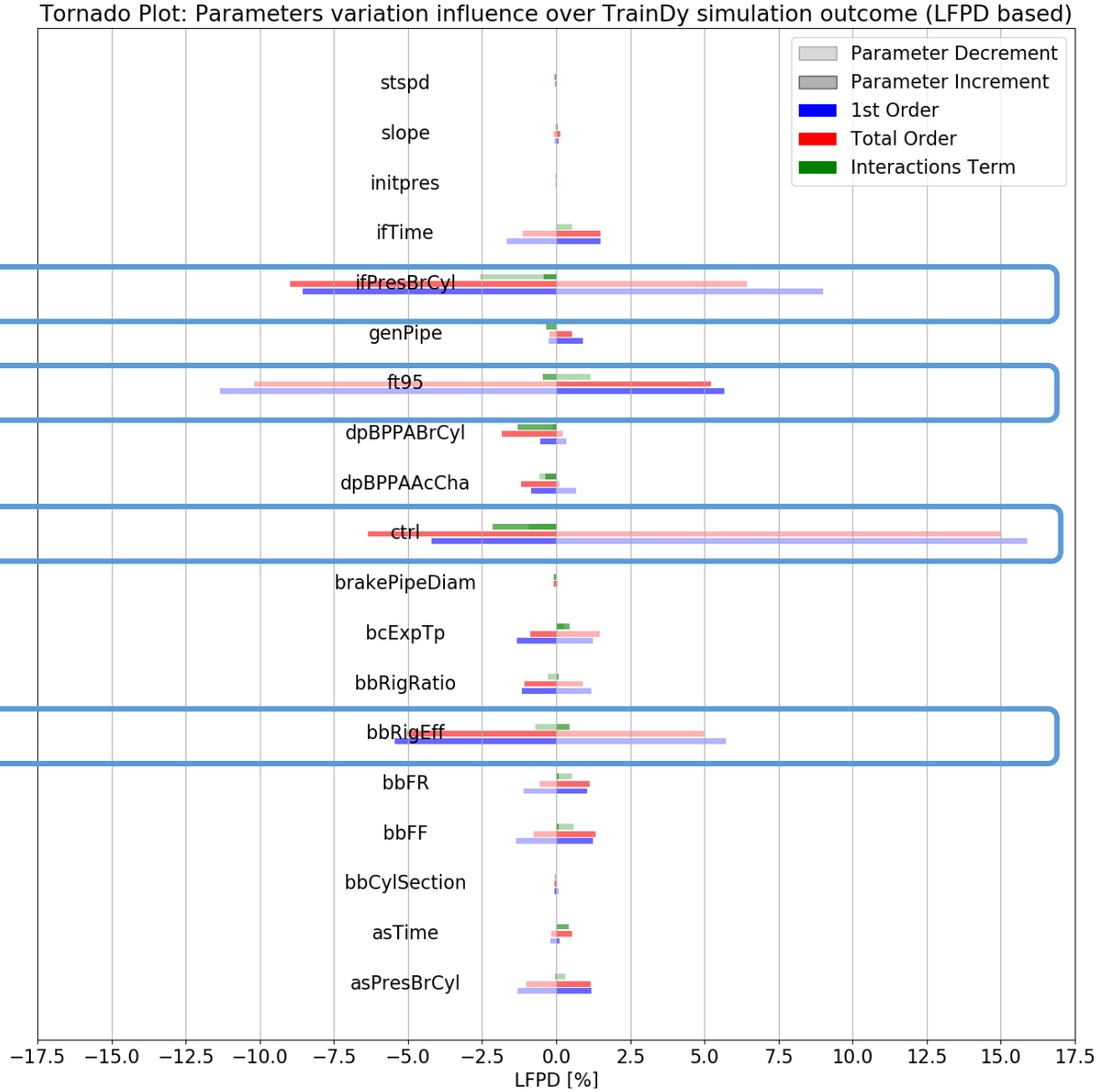
# Results: Tornado Plots (1/3)

T2_740, EB

## LTF



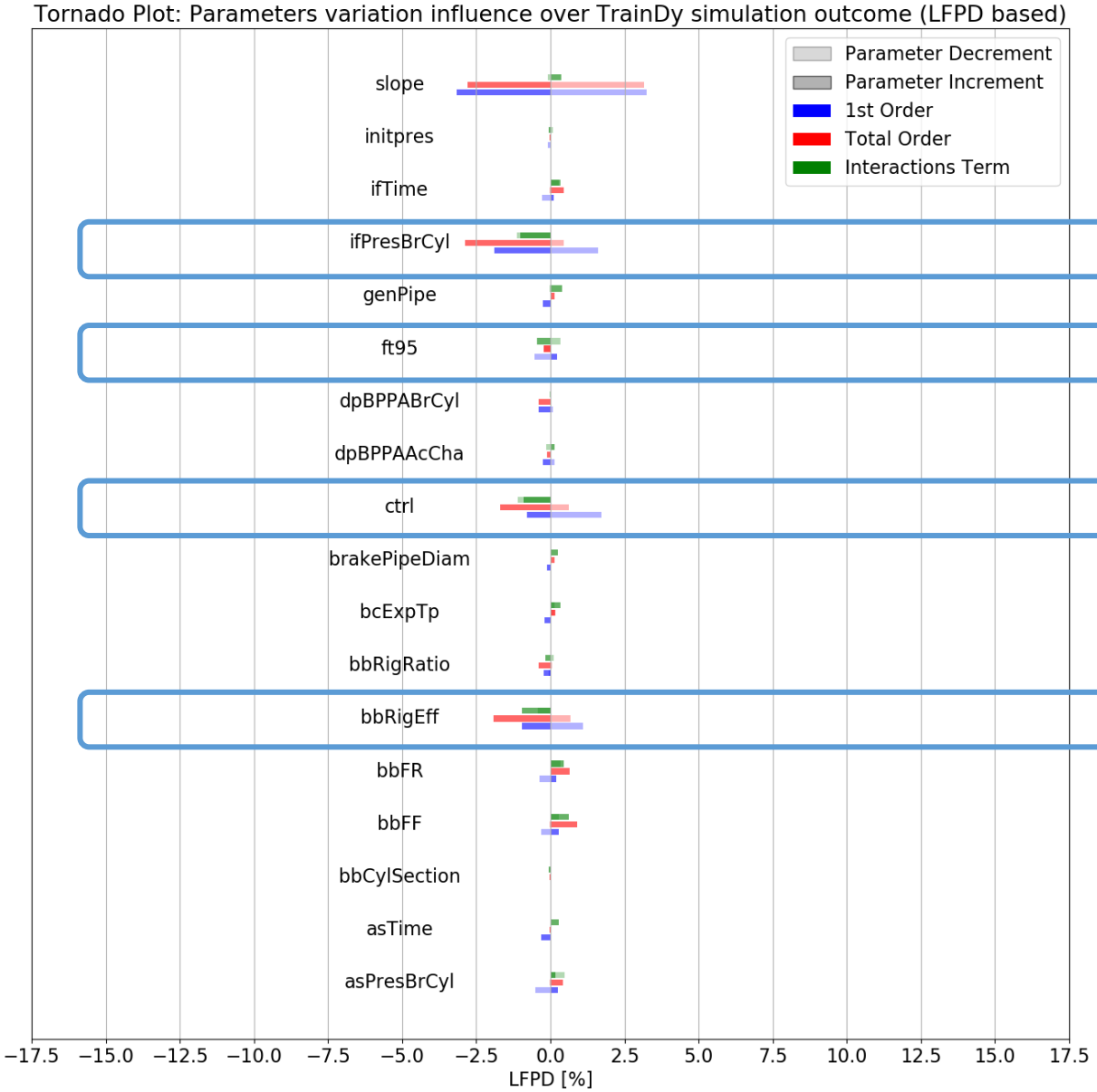

## LCF



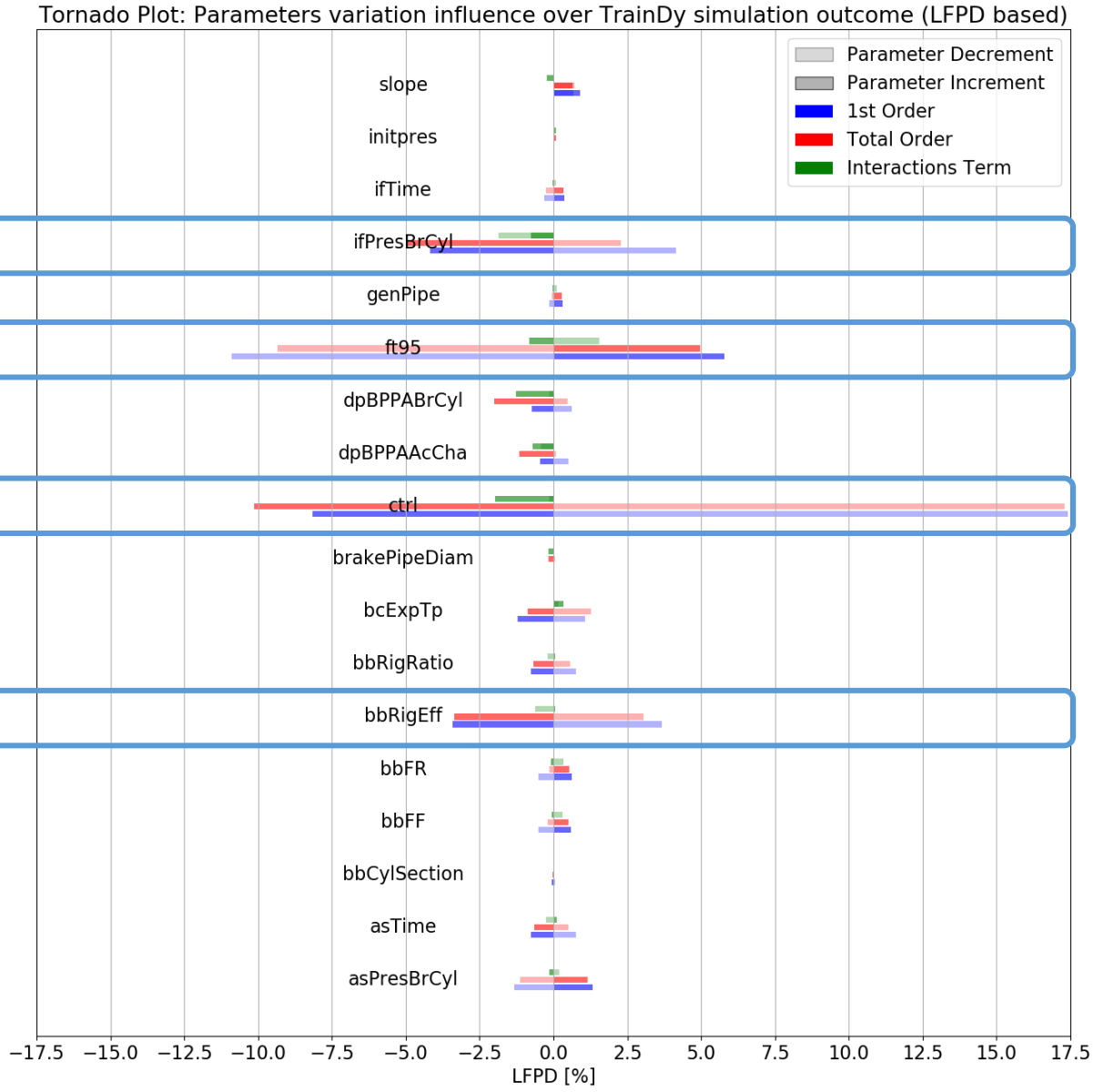
# Results: Tornado Plots (2/3)

T2_740, T-EB

## LTF



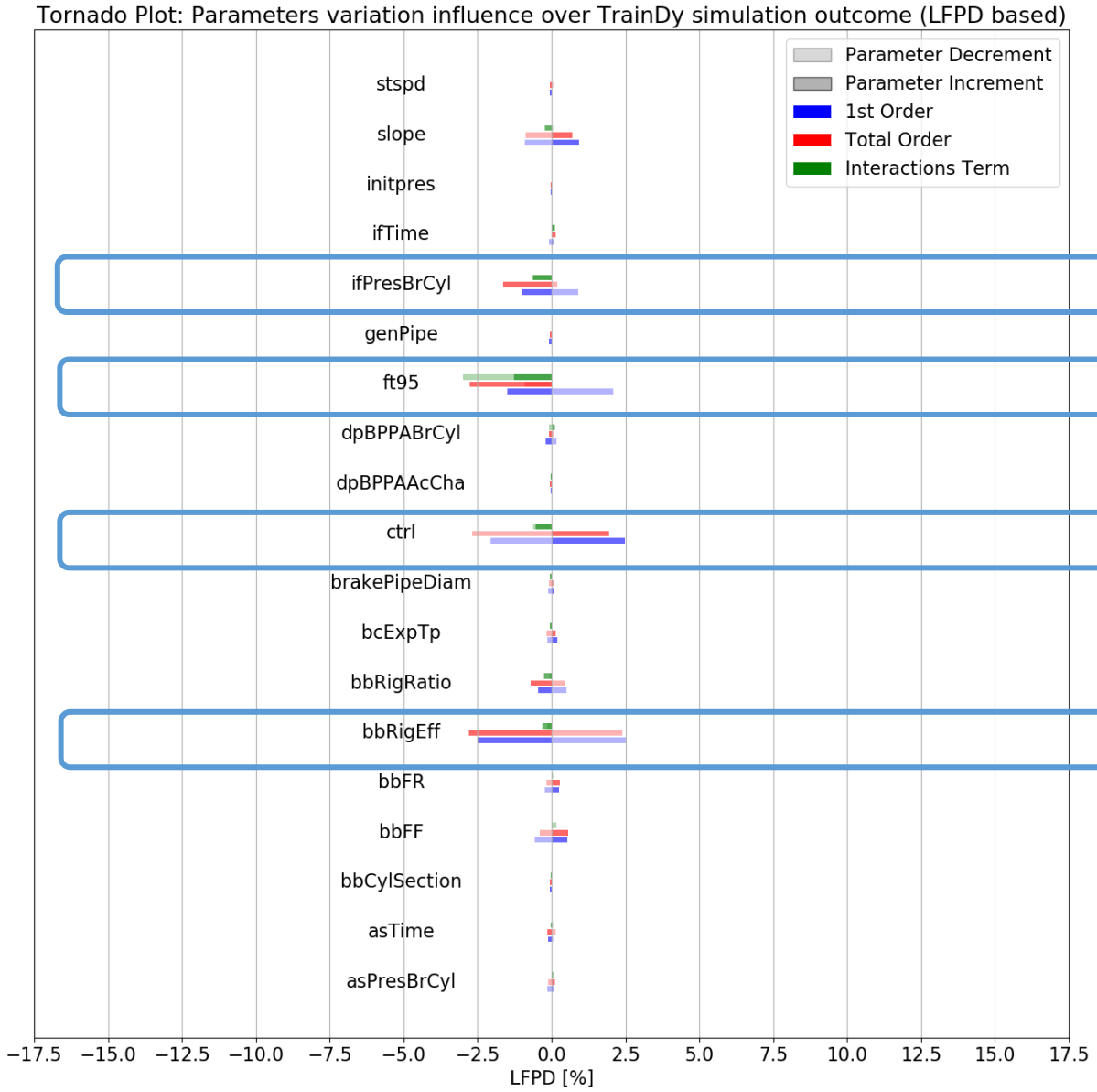

## LCF



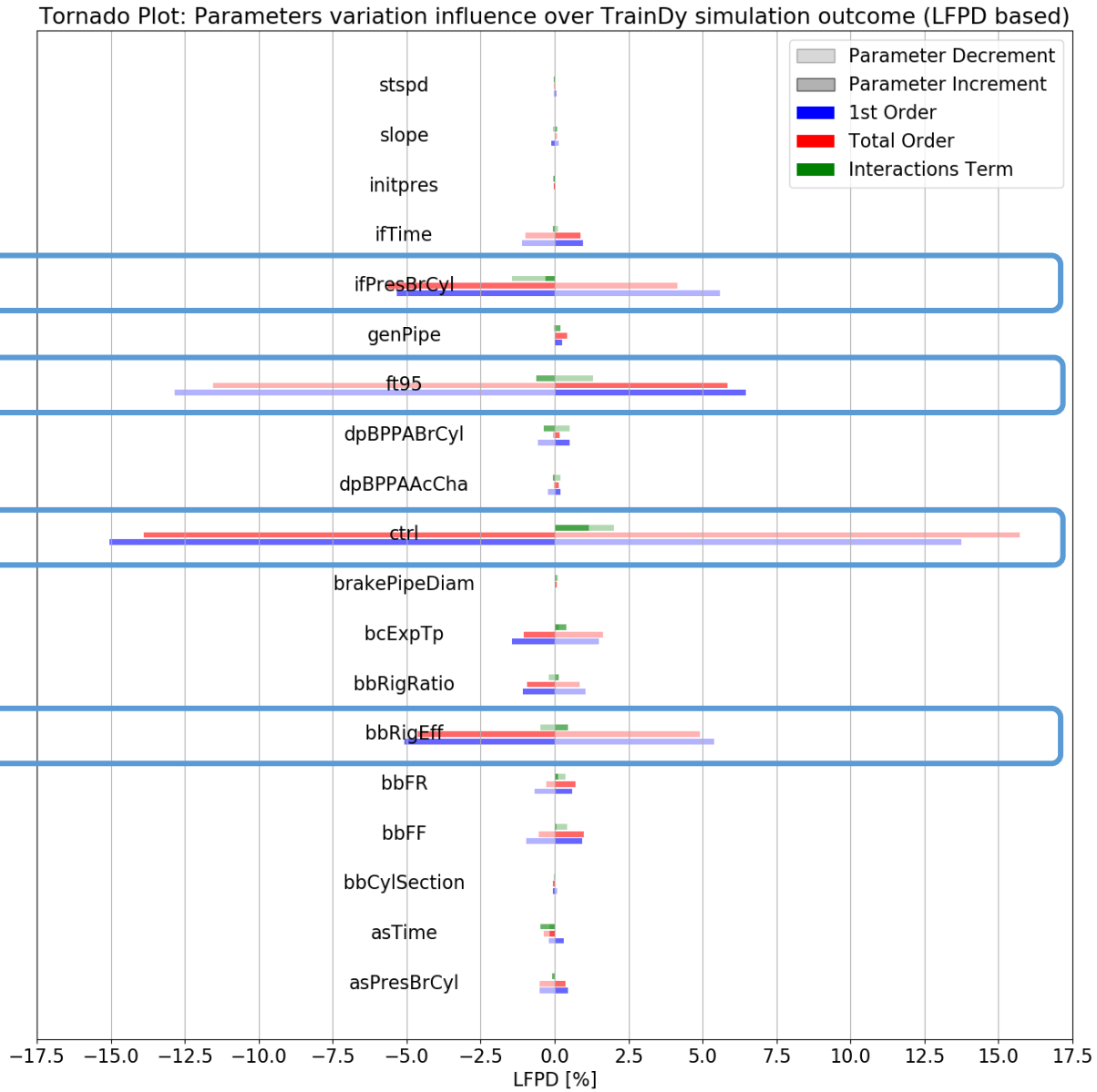
# Results: Tornado Plots (3/3)

T4_1500, EB

## LTF




## LCF



# Maximum train length/hauled 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 |

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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)

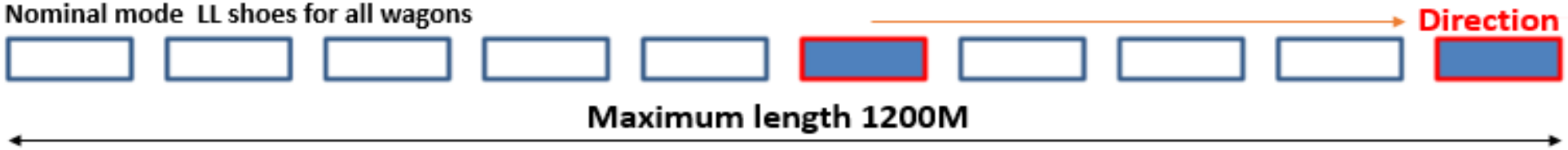
**Nominal mode, LL shoes for all wagons**

**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 |

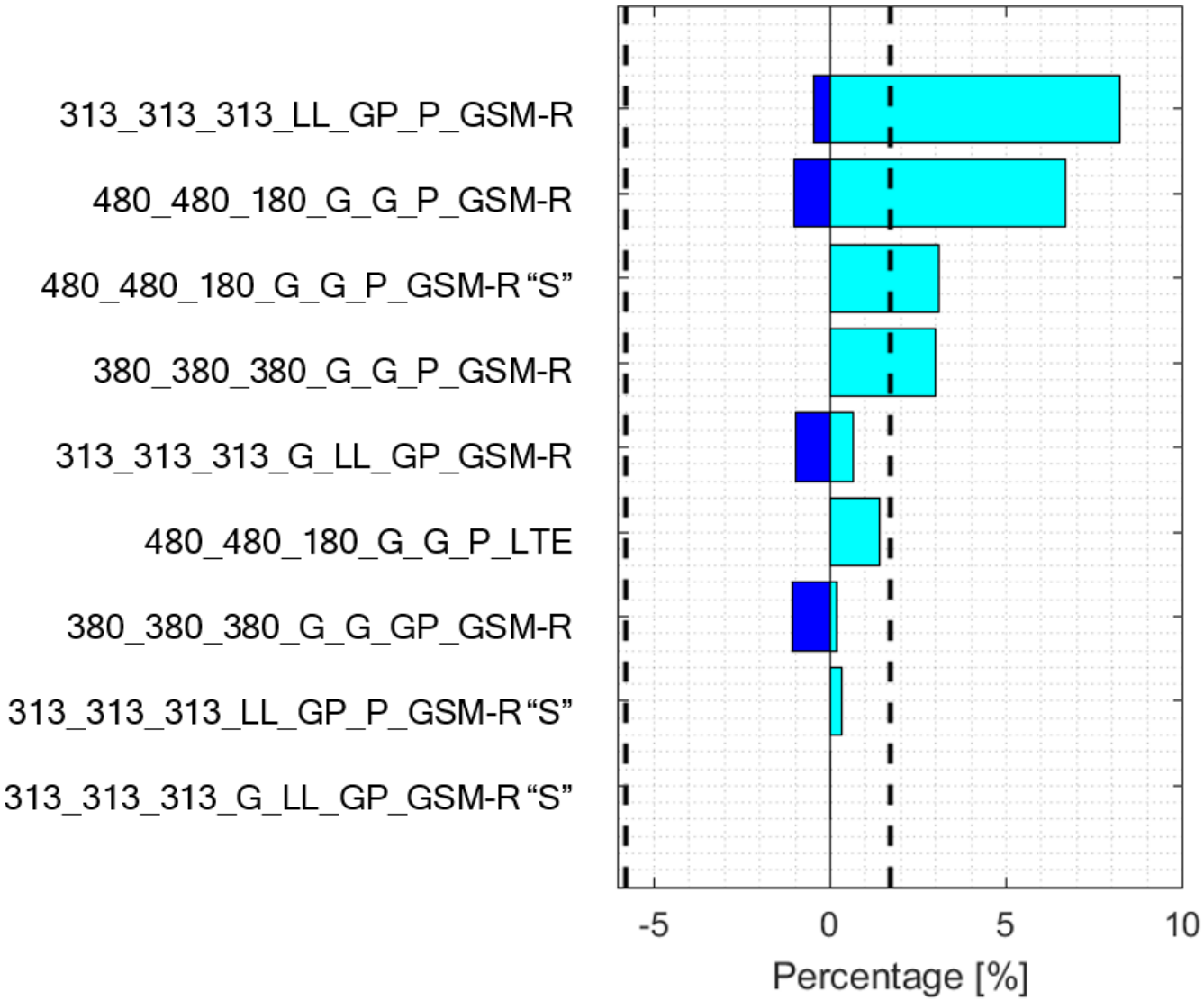
Coupled trains of combined transport with 2TUs 100km/h homogeneous wagons flat with bogies 2.6T/m average load but random loading or heavy ore homogeneous trains coupled with container trains behind

**Nominal mode LL shoes for all wagons**




| 1st 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 |
| 2nd 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 | | | | | | | | | | | | | | | | | Fig.35 | | | |
| | 800-1200T | | | | | | | | | | | | | | | | | | 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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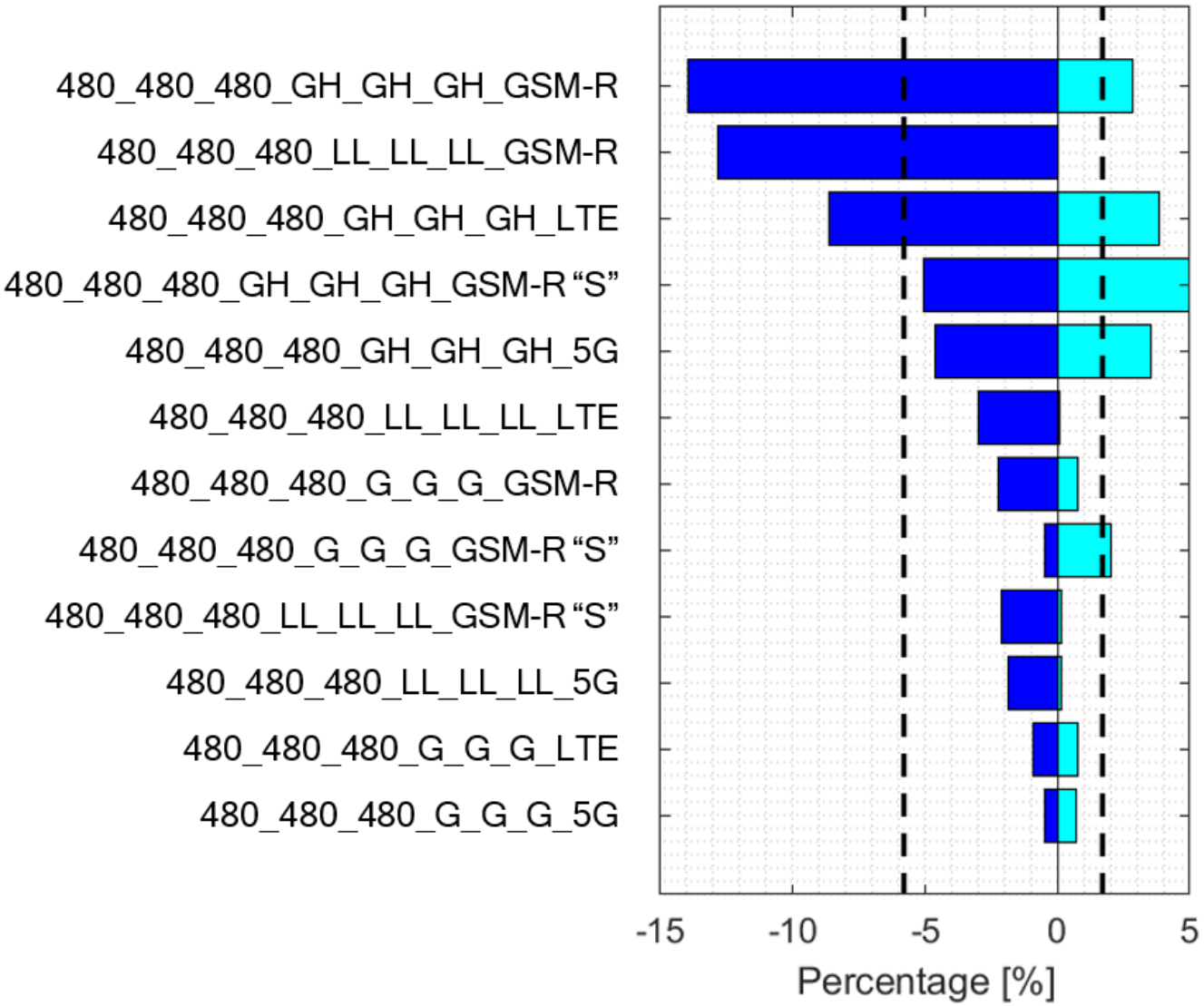
# 3T and remote TU in T-EB, radio GSM-R, LTE and 5G




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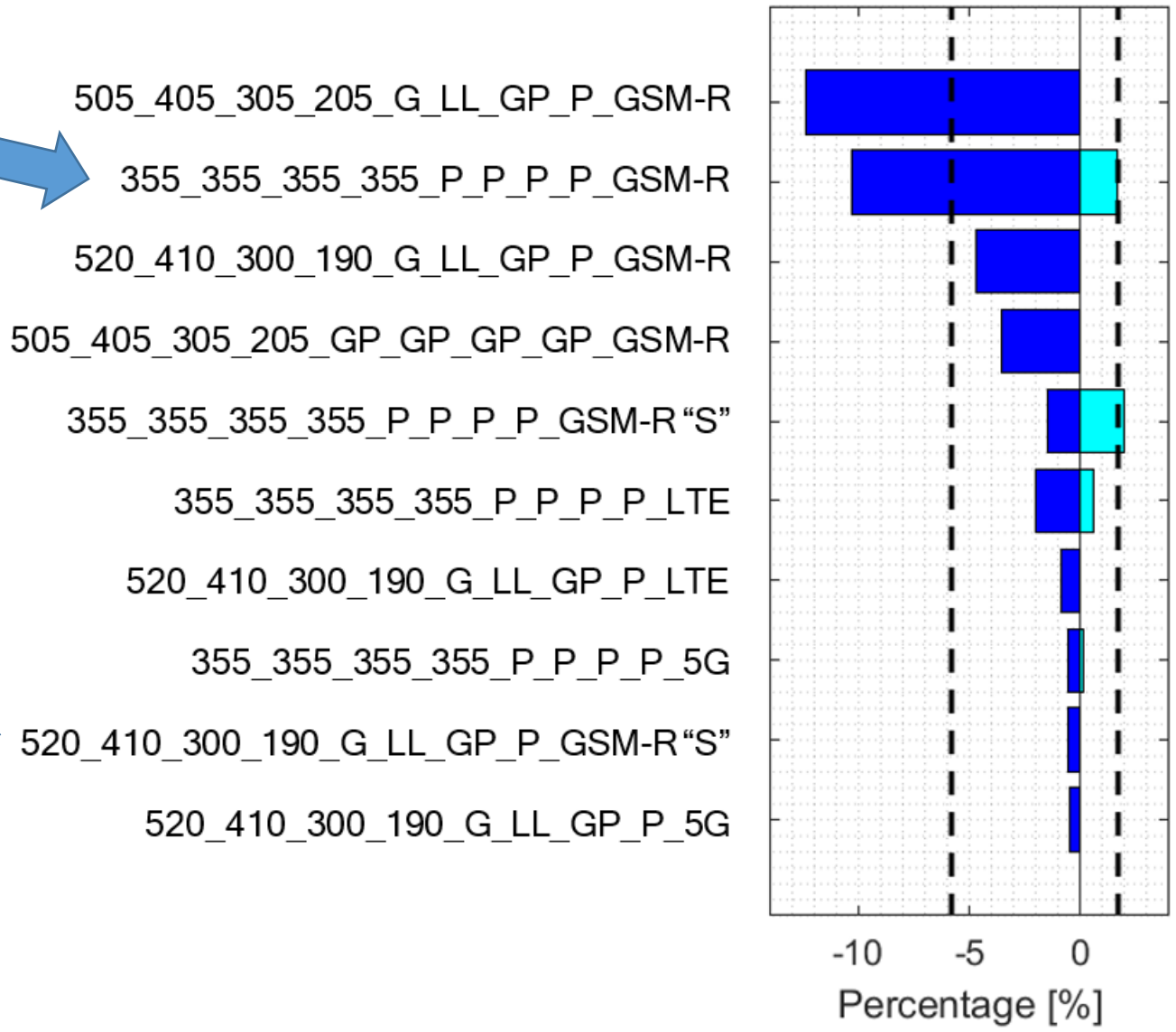
# 4T in T-EB, radio GSM-R, LTE, 5G and synchro braking

*Coupling similar trains, in terms of length and mass is not the best option:*
*355_355_355_355_P_P_P_P*

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*





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# Conclusion

- Methodology to compare the safety performance expected for different train families
  - Definition of Lower Force Probability Differential (LFPD) as statistics to compare Longitudinal Forces of train families
- Identified the most relevant parameters for LTD: they match the Railway Undertakings experience.
- Find several train consists with 2, 3 and 4 TU having the same level of safety (in terms of LTD) of current trains, with different radio technologies: GSM-R, LTE, …

➢ Application of the statistic methodology to test demonstrators.

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