Report

3rd TrainDy Study
Evaluation of different approaches to operate Articulated Wagons in Freight Trains above 1600 tons

Document: 22-69976-3rd-TrainDy-Study
Date: 28.04.2023

Department: Bremstechnik, Tür- und Einstiegssysteme
TT.TVE 311

Change History

Version	Date	Summary of changes
1.0	24.04.2023	Draft version
1.1	28.04.2023	TVE311 internal approval

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References

[1] ***DB Systemtechnik GmbH*** Offer 69976-001-0, 2022-06-15

[2] ***DB Cargo AG*** Order 69976-001-0, 2022-08-31

[3] ***DB Cargo AG*** Train Formation Data including train id with wagon sequence and related data, data size: 3.8 million wagon entries, provided during EU project FFL4E (Future Freight Locomotive for Europe), period 2016-11-01 to 2017-03-31

[4] ***UIC*** IRS 40421, Rules for the consist and braking of international freight trains, 1st edition, 2021-12-1

[5] ***L. Cantone***, Effective ways to compare two families of freight trains, IOP Conf. Series: Materials Science and Engineering, 51° Conference on Engineering Mechanical Design and Stress Analysis, 2023

[6] ***Agency for Railways***, Operations and traffic management system TSI, Acceptable means of compliance on checks and tests before departure, including brakes and checks during operation, European Union, 2022-07-12

[7] ***L. Cantone***, Deliverable D 3.3: TrainDy simulations for experimental tests, Shift²Rail Joint Undertaking, EU project Horizon 2020, 27.11.2020

[8] ***R. Karbstein***, DB Systemtechnik GmbH, Power Point slides, file: Presentation_3rd_TrainDy_Study-v0.1.pdf, presented during CEF PSA UBS Action Project Final Conference on 29.11.2022

[9] ***R. Karbstein***, DB Systemtechnik GmbH, Power Point slides, simulation update, file: Presentation_3rd_TrainDy_Study-Update1-v0.1.pdf, sent by e-mail 15.12.2022

[10] ***R. Karbstein***, DB Systemtechnik GmbH, Power Point slides, simulation update, file: Presentation_3rd_TrainDy_Study-Update1-1900t-v0.1.pdf, sent by e-mail 16.12.2022

[11] ***R. Karbstein***, DB Systemtechnik GmbH, Power Point slides, final simulation update, file: Presentation_3rd_TrainDy_Study-v1.0.pdf, sent by e-mail 06.02.2023

List of Abbreviations

Brake Regime	Synonym to Brake Position
EB	Emergency braking
LCF	Longitudinal Compression Force
LL	Brake Regime “Long Locomotive”
P-trains	Trains that have most of the wagons set to brake position P
TLCF	Tolerable Longitudinal Compression Force
T+EB	Traction interrupted by emergency brake intervention
UIC	Union Internationale des Chemins de fer
XLL	Extended LL Regime (Locos and first 7 wagons in Brake Position G)

1 Contract Details

1.1 Order

Based on the offer [1], which originally was sent to UIC, DB Systemtechnik GmbH has been assigned by DB Cargo AG via order 69976-001-0 [2] to undertake the study at hand.

1.2 Contracting Parties

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Distribution List:	Digital Report in Portable Document Format (*.pdf): Lukas.Joa@deutschebahn.com

1.3 Clarification

This report frequently uses terms like train mass or mass of the train. This term refers to the hauled mass of the train and does not include the mass of the locomotives.

A certain number of trains virtually built under the same conditions is named train family.

1.4 Description of situation

There are ongoing activities to support the UIC/Xrail cooperation for the CEF PSA UBS Action project[1] which is aiming to identify and solve issues to interoperability, hampering international Rail Freight Traffic, especially on Rail Freight Corridors as well as make European Single Wagonload a more competitive and more sustainable alternative to road transport.

[1] The CEF PSA UBS Action Project was launched to resolve the technical operational issue of different national braking rules and requirements along with the implementing of the Unified Braking Scheme (UBS) as a pilot project along the Rhine-Alpine Corridor.

Two TrainDy[2] studies were released in the past. The report of the first study, carried out by SNCF and described in the last TrainDy activity report, is published on the UIC ETF shop as report B 177.4 / RP 5. Its results have been considered in the first edition of IRS 40421 [4], now referenced into the AMOC [6].

A second technical study has been released recently, dealing with the integration of articulated wagons in trains with a total mass higher than 1600 t and a rearrangement of the wagon order to tolerate wagon masses lower than 32 t and 40 t respectively. In addition, the potential of increasing the total train mass by running up to seven wagons in brake position G at the head of the train was investigated. Also, the effect of the track radius was considered by applying extrapolation rules of IRS 40421 to get estimations of tolerable forces. All those studies have been performed based on a relative approach by comparing the results with a reference system that is regarded as a safe operational system.

Due to the special nature of articulated wagons, which normally have a shared Jacobs' bogie between the two sides of a wagon, they can experience remarkable differences in individual axle loads in case of uneven loading. As a result, one of the end bogies may have a much lower axle load than the others, meaning that the risk for derailment in case of excessive longitudinal compressive forces is increased. Therefore, it is not possible to apply rules that are normally applicable to regular axle and bogie wagons without additional safety precautions.

As for the current IRS 40421, articulated wagons are only allowed in P-trains of up to 1600 t. However, this places rather severe boundaries to the business opportunities of rail freight operators, which can therefore not use the full capacity of a train or they are forced to run in a less efficient brake position G. Operation of G-trains uses up more track capacity due to lower average speed compared to other traffic (e.g., freight trains in position P or passenger trains), thus increasing timetabling complexity and reducing path availability.

In the previous studies, a weak point was the consideration of those articulated wagons in combination with an appropriate reference train family. To overcome the problems related to articulated wagons this third TrainDy study was performed.

1.5 Tasks

It shall be demonstrated by means of statistical TrainDy simulations how much heavier P-trains could be when containing articulated wagons and if additional mitigation measures for the limitation of Longitudinal Compression Forces would be put in place. The study must therefore perform a comparative analysis of a reference system currently allowing articulated wagons against a proposed system allowing heavier trains but by applying compensation measures one-by-one as well as in combination.

The study is primarily focused on derailment risk and secondarily on train disruption risk. Therefore, the change of longitudinal forces is investigated. The effect of the proposed mitigation measures in terms of stopping distances is not subject of the study.

The reference system is defined as follows: P-trains in the range of 1200 – 1600 t (either a train exclusively formed of articulated wagons or a mixed consist, evoking highest LCF).

[2] TrainDy is a simulation software that enables to simulate the longitudinal dynamics of trains. Originally, the main software features had been developed by University of Rome, Tor Vergata, with the support of Faiveley Transport. Today the software is further developed and maintained by the UIC special group TrainDy.

LCF compensation measures to be analysed (simulation variants):

- Variant 1
  Reference train family with Brake Regime XLL (extended "Long Locomotive") (ref. [8], [11])
- Variant 1b[3]
  Reference train family with Brake Regime XLL, new mass range 1600 – 1900 t, no minimum wagon mass limit (ref. [10], [11])
- Variant 2
  Reference train family with Brake Regime XLL, new mass range 1600 – 2200 t, minimum wagon mass of 26 t (ref. [8], [9])
- Variant 3
  Reference train family with Brake Regime XLL, new mass range 1600 – 2200 t, minimum wagon mass of 26 t, shifting articulated and permanently coupled wagons to end of train (ref. [8], [9])
- Variant 4
  Same as Variant 3, just in reverse order (running in the opposite direction) (ref. [8], [9])

2 Main Steps of the Study

2.1 Definition of a suitable Reference System

Mixed train consists of mass-ranges between 1200 and 1600 t running in brake regime LL evoke a high level of LCF. Especially trains close to 1600 t can be found frequently because operators try to avoid running in Brake Regime G with correspondingly lower speeds. Therefore, this LL operation can be considered as a representative scenario that is considered save.

In a first step the tendency of the above listed simulation variants has been investigated in terms of their longitudinal response and whether the applied compensation measure is beneficial or not ([8], [9] and [10]). This is realised by simulating smaller samples of trains. Train models have a train mass of 1200 to 1600 t.

At a later stage, after identification of beneficial scenarios, those scenarios were investigated by a high number of simulation samples [11]. For these simulations, the reference system has been concentrated to LL trains with a quite small mass range between 1550 and 1600 t. A reason for this rather punctual comparison minimizes any impact on the results due to different mass ranges between reference and variant scenarios. In a similar way as presented in recent publications [5] the assumption in the study has been a linear increase of masses

$$M_{new} = M_{new,min} + \frac{(M_{new,max} - M_{new,min})}{(M_{ref,max} - M_{ref,min})}\,(M_{ref} - M_{ref,min})$$

Equation 1: Mass increase from reference system M_{ref} to new system (variant) with new mass M_{new}

and is probably not realistic.

2.2 Building Virtual Trains

A large data set [3] of freight train formation had been made available by DB Cargo AG in the framework of the EU project FFL4E. This data set was filtered as follows: only trains are considered that have at least one intermodal wagon.

Analysing this filtered data set the train mass distribution, the cumulative probabilities of the pay load distribution as well as of the group size (number of subsequent wagons having same

[3] Variant 1b was not part of the original simulation task but came up during the presentation of first results [10] and this variant is considered beneficial for freight train operators.

wagon type and pay load) are determined. These distributions form the basis of the virtual train formation process described in the IRS 40421 [4].

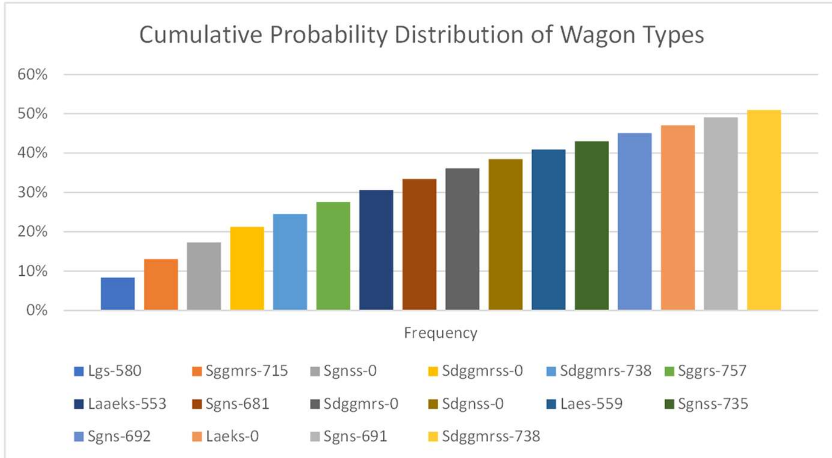


Figure 1: Cumulative histogram of wagon types for intermodal trains, extracted from data sample of DB Cargo AG [3]. The wagon types shown represent 50 % of the total running distance of all wagons within the data sample.

Figure 1 shows the most relevant wagon types covering 50 % of the overall kilometric performance of the data sample. To limit modelling efforts[4], the number of representative wagon types is limited to the number that represents 80 % of the total kilometric performance. This reduced wagon database for simulation is supposed to be representative in terms of scatter of wagon length, wagon mass and coupler equipment.

Additionally, the cumulative probability distributions of wagon load and group size[5] of each relevant wagon type have been determined. As an example, Figure 2 shows the statistical analysis of wagon type Sggmrs 715. Most of the wagon groups consisting of wagon type Sggmrs 715 have up to 5 wagons (90 % have 5 or less wagons forming a group). In about 10 % of all loading cases the wagons are running as empty wagons.

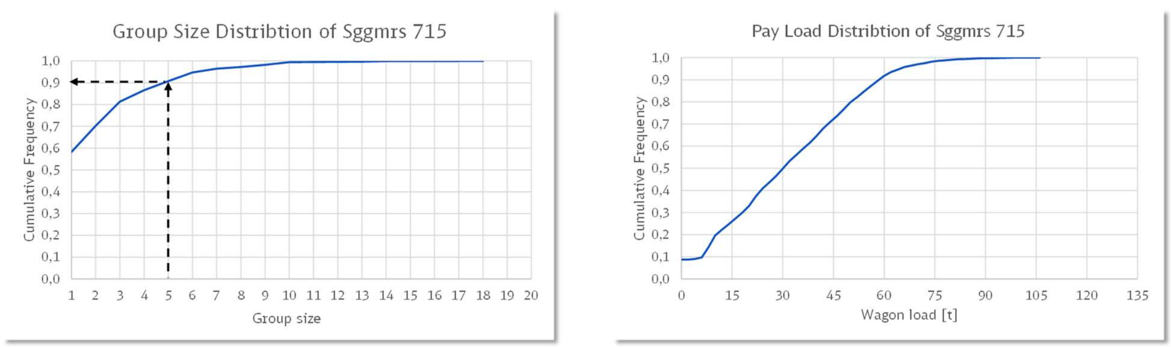


Figure 2: Group size (left) and pay load (right) distribution of intermodal wagon type Sggmrs 715

The resulting distribution of the maximum LCF of all trains is quite stable when approximately 1.000 trains are built and simulated.

2.3 Virtual Target Trains

Target trains consist of the reference trains but have a higher pay load and include compensation measures. As already described in section 2.1, the mass range of the reference trains is

[4] Up to now wagon models have to be built manually which is a time-consuming task because technical information about wagons is not always easily accessible.

[5] The group size refers to the number of successive wagons of the same wagon type forming a group

linearly mapped to a higher mass range. It is crucial to notice that the study is robust due to the following properties:

- the study is based on relative approach
- the study uses exactly the same wagon types and the same number of wagons for each train

Only the wagon mass, the train's brake regime and the wagon sequence may differ.

2.4 **Assessment Criteria**

The relative comparison of the longitudinal dynamics of different train families is based on the following assessment criteria:

- LCF10m
  Minimum value of LCF acting on buffers within a running distance of 10 m
- LCF1s
  Minimum value of LCF acting on buffers within a time frame of 1 s
- LCF-Ratio
  Ratio of LCF acting on buffers and maximum LCF that a wagon can support under certain conditions (TLCF)

TLCF depend on various operational parameters like pay load and adjacent wagon as well as on technical parameters like buffer plate geometry, track curve radius, type of running gear, car body stiffness etc.. Currently, the maximum LCF is computed based on extrapolation rules published in IRS 40421 [4]. A ratio lower than minus one is associated with a potential derailment, thus must be avoided.

Articulated and permanently coupled wagons are more complex in terms of derailment prediction. There is no rule in IRS 40421 how to compute TLCF for that kind of wagons. To provide a safe assumption on TLCF those wagons are virtually split in two parts, both considered as two-axle wagons, so that the TLCF of each part can be computed based on the IRS as well.

The assumption on the load distribution of an articulated wagon is done in a way that one part of the joint-connected wagons is laden up to the maximum value that has been observed in the data set [3] and the other part carries the rest of the pay load. The mathematical pendant is set out in Equation 2.

$$L_{High} = \min\left(L,\ \frac{L_{Wagon,max}\,^{*}}{2}\right);\ L_{Low} = L - L_{High}$$

Equation 2: Assumption on mass distribution for articulated and permanently coupled wagons

The assumption above frequently leads to unladen wagon parts. The wagon's TLCF is computed based on the unladen part, i. e. there is always an unfavourable load distribution assumed.

For the application of IRS 40421 a track radius of 190 m is assumed in analogy to the previous TrainDy studies. Distinctions regarding buffer plates are ignored as trains are simulated on a straight track.

2.5 Relevant manoeuvres

The decision which manoeuvres shall be analysed are derived based on the conclusions of Shift2Rail projects [7]. These manoeuvres provoke a high level of longitudinal forces:

- Emergency braking from coasting
- Emergency braking during braking

Both manoeuvres have an initial speed of 30 km/h in common when the emergency brake is applied.

3 Results

3.1 Introduction

The results of the study are expressed in different ways. The typical diagrams used are explained in the following sections

3.1.1 Cumulative Probability Distributions

One typical diagram is dealing with cumulative probability curves as shown in Figure 3. It means that 90 % of all wagon groups have a size of 5 or less, or vice versa, 10 % have a size greater than 5. During the virtual train formation process for each varying parameter of each wagon and each train a random number between 0 and 1 is provided. With this random number the corresponding abscissa value of the cumulative distribution is inversely determined.

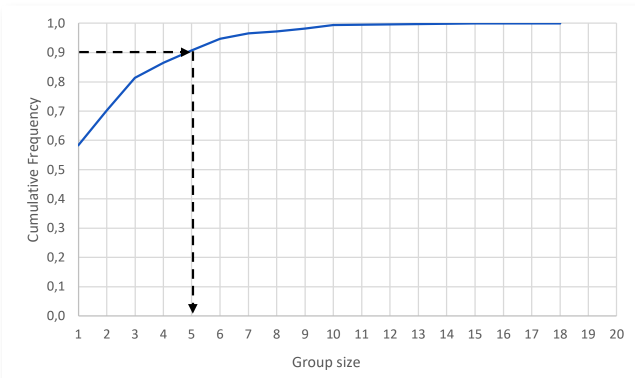


Figure 3: Display option: cumulative probability distribution. Here dealing with the group size[6]

[6] number of subsequent wagons of the same wagon type

3.1.2 Boxplots

Another type of results are box plots as shown in Figure 4. The meaning of the box is that 50 % of all values are inside of this rectangle. Starting from the abscissa. Between the abscissa and the upper boundary of the box there are 25 %, between abscissa and median there are 50 % and between the lower boundary and the abscissa there are 75 % of all values.

The most exterior horizontal lines correspond to the whiskers. They are set in a way that 99.3 % of all values can be found between the whiskers. Outside of the whiskers there are 0.7 % of all values indicated as single values of the so-called outliers.

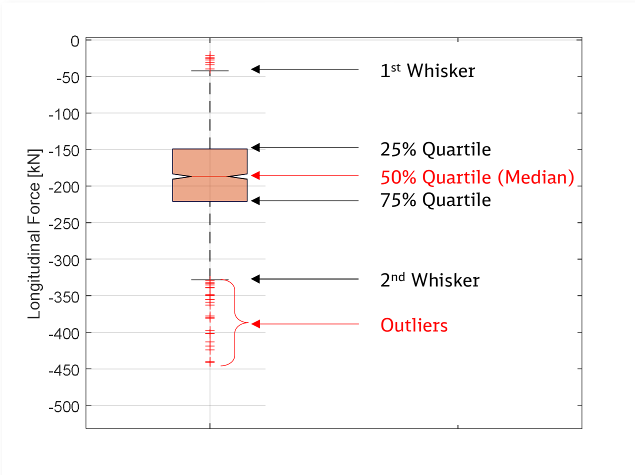


Figure 4: Display option: Boxplot

3.1.3 Quartile Plots

Finally, another helpful way to express results is the quartile plot that can be used if each result (each point) has a corresponding counterpart and thus occurs with the same probability. First the results are sorted in ascending order for both, result A and result B in Figure 5. Then each data pair with the same quartile is printed (first with first, second with second in the list etc.). If alle points are coincident with the black diagonal it means that result A and B belong to the same distribution. Quartile plots are typically shown with positive numbers. Therefore, in this case the axes show absolute values for the compression forces.

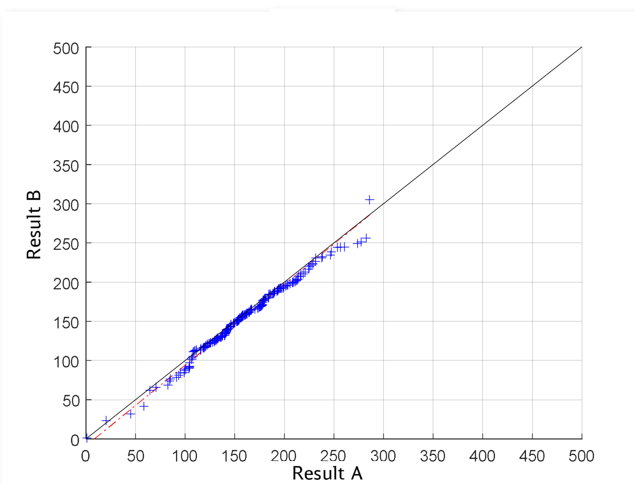


Figure 5: Display option: Quartile Plot

Results may be expressed on wagon or train level. The term “wagon level” indicates that for example the maximum longitudinal compression force of each wagon is considered. If the term “train level” is referred, it means that only the maximum of all wagons in the train is considered.

Furthermore, confidence intervals are used when defining the probability of derailment. The given intervals refer to a confidence value of 95 %. As an example, if the confidence interval is ranging between 0.1 and 0.2 % it means that with a probability of 95 % it is true that the real portion of derailment is in between the boundaries of the confidence interval.

3.2 **Emergency brake from coasting**

3.2.1 Variants 1-4, target mass range 1600–2200 t, 26 t min. wagon mass, 200 samples

3.2.1.1 Description

Simulations with 200 samples are a pragmatic and fast way to identify promising operational scenarios as well as risky ones. For a final usage as a part of a superior risk analysis larger samples are needed to reach a converging distribution of longitudinal forces.

Figure 6 gives an overview of the train mass distribution of the reference case and information concerning the sufficiency of the sample size.

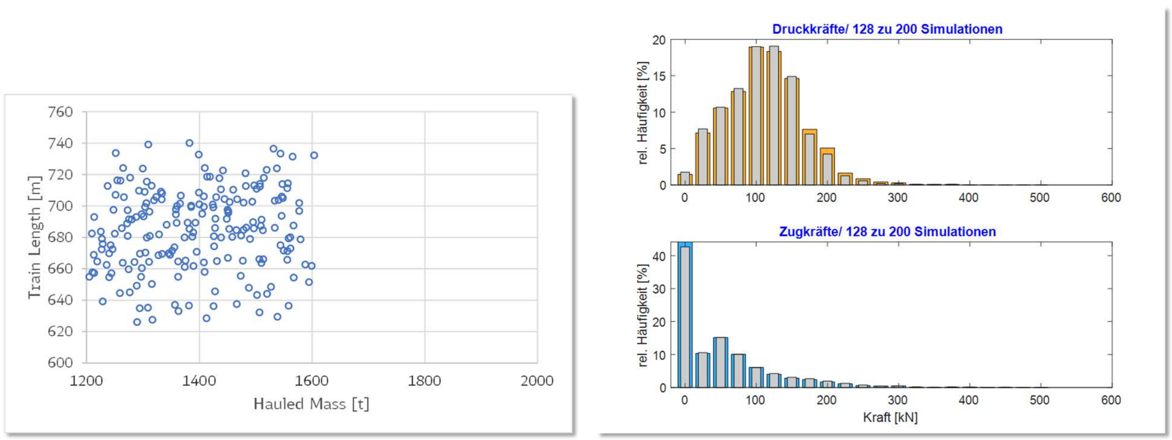


Figure 6: Distribution of hauled train mass as scatter plot on the left. On the righthand side: histogram showing the distribution of maximum occurring longitudinal force for all samples (trains) in the reference when comparing 128 versus 200 samples

On the right-hand side the figure shows the distribution of maximum longitudinal forces for compression (upper diagram) and tension (lower diagram) as histograms. The grey and thinner columns indicate the distribution of 128 samples and the columns coloured in orange refer to 200 samples. There is a sufficient similarity of the grey and the coloured bars in terms of their height. Therefore, the sample size proves to be sufficient to determine the tendency of the different variants that will be compared in the following sections. On the left-hand side of the figure the hauled train masses of the sample are shown as scatter plot.

3.2.1.2 Comparison of LCF

Figure 7 compares the distribution of the minimum longitudinal compression forces within a running distance of 10 m.

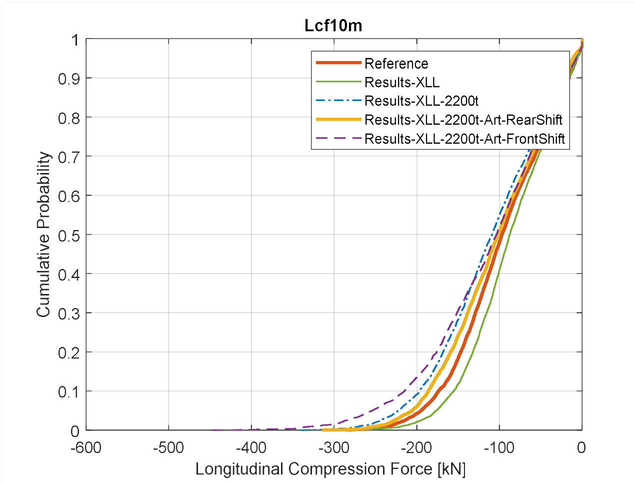
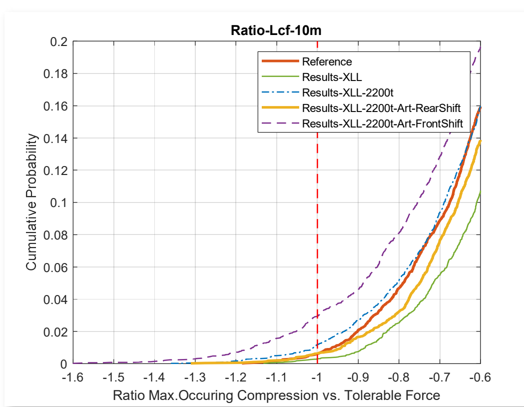


Figure 7: Longitudinal Forces within moving distance of 10 m, reference and variants 1 to 4

The figure shows that the mass increase to 2200 tons leads to significantly higher 10m-compression forces compared to the reference, especially for the case when all articulated and permanently coupled wagons are shifted to the front end of the train just behind the locomotives (see dashed line on the very left). Also, in the case of shifting intermodal wagons to the end of the train there is a worse dynamic compared to the reference. This is because intermodal wagons are frequently equipped with an automatic load weigh device. Those devices have a harmonizing effect on longitudinal dynamics but at the end of the train with a usually lower level of compression forces they cannot unfold their harmonizing effect.

3.2.1.3 Ratio of LCF to TLCF

This section deals with a potential derailment of wagons. Figure 8 compares the probability of potential derailment of reference and variants.



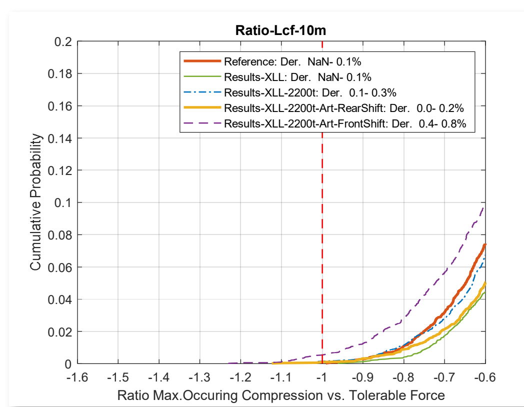


Figure 8: Ratio of actual 10m-force vs. tolerable force, target 2200 t, reference and variants 1 to 4, left figure: max. TCLF of 240/400 kN for 2-axle/bogie wagons; right figure: max. TCLF 400/600 kN.

In this consideration the ratio of compression forces does not confirm the feasibility of the target mass range as the frequency of samples below minus one is much higher when intermodal wagons are shifted to the front (see dashed line, last entry in legend).

The study has been performed with different assumptions to check the overall validity of the relative approach. The left diagram of Figure 8 is applying restrictive values for the maximum possible TLCF of 240 kN for 2-axle wagons and 400 kN for bogie wagons. IRS 40421 [4] instead accepts higher values for the maximum possible LCF. In both cases the front shift variant is not acceptable.

Proceeding with the higher values of the IRS (400 and 600 kN) and therefore focusing the right diagram of Figure 8, rear shifting seems to be comparable with the reference because the curves seem quite coincident for values lower than -0.9. However, the upper value of the confidence interval shown in the legend is 0.1 % higher (0.2 % instead of 0.1 %).

The lower boundary of the confidence interval of the reference is defined as “NaN”[7] and indicates that there was no value below minus one at all in the computed sample. Variant 2 (Results-XLL-2200t with mass increase to 2200 t but no shifting of intermodal wagons to favourable locations) is very likely worse than the reference as its confidence interval is ranging between 0.1 to 0.3 % and does not overlap with the interval of the reference.

3.2.1.4 Assessment of variants 1 - 4

To ensure a safe operation, the target mass must be significantly lower than 2200 tons. Also, a shunting process which would include shifting of intermodal wagons to the front or rear end of the train can be expected as cost and time intensive.

Therefore, during the study a new variant came up dealing with a lower train mass limit but without the need to consider any other measures like minimum wagon mass or wagon position in the train. The results of this new variant are presented in the following section 3.2.2

3.2.2 Variant 1b, target mass range 1790–1900 t [8], 2000 samples

3.2.2.1 Description

Simulations with 1000 samples or more allow a proof of concept and are used do demonstrate a safe operation when dealing with an accepted reference system.

Figure 9 shows the distribution of longitudinal forces for compression (upper diagram) and tension (lower diagram) and the mass distribution of the reference.

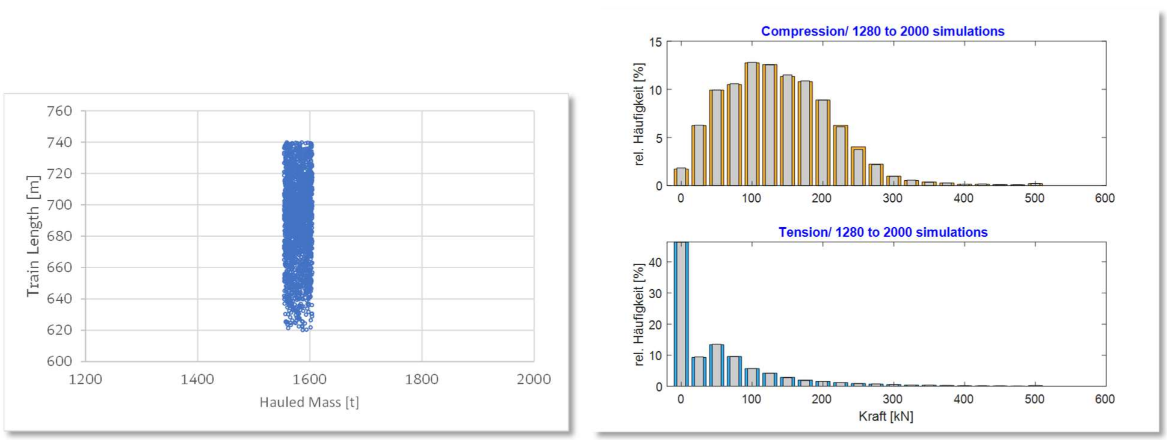


Figure 9: Left diagram: distribution of hauled train mass as scatter plot. Right diagram: histogram of maximum longitudinal forces on train level for variant 1b.

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[7] Not a Number

[8] In the section title, the value of 1790 t instead of 1600 t is due to application of Equation 1. The value is related to a smaller mass range of the reference. Of course, the conclusions here are valid also for the wider mass range of 1600 – 1900 t.

The thin and grey columns of the histograms refer to 1280 samples and the columns coloured in orange indicate the distribution for 2000 samples.

This time a smaller mass range has been used for the reference to allow a more punctual comparison by minimizing any eventually adulterant effect due to a different size of mass range[9] (s. section 2.1).

3.2.2.2 Comparison of LCF

The distribution of longitudinal compression forces is very similar for reference and variant 1b. Figure 10 shows a slightly higher median and slightly lower whisker of the reference (see boxplots on the left).

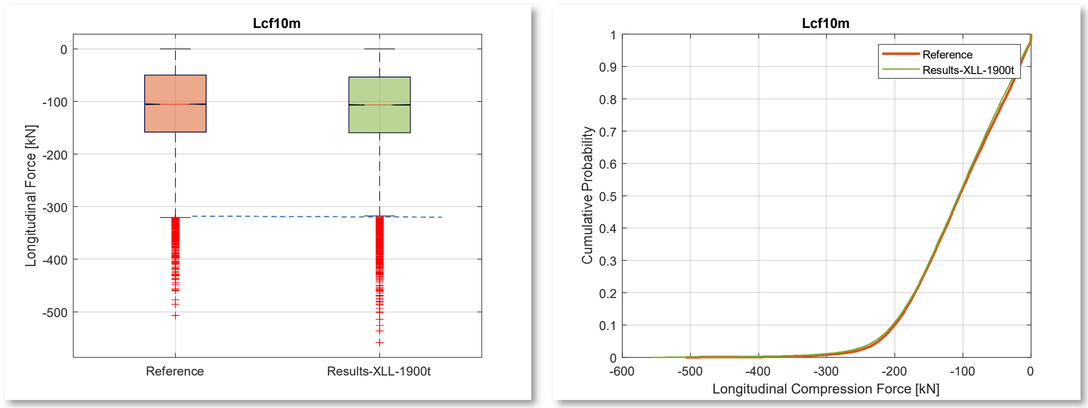

Figure 10: Longitudinal Forces within moving distance of 10 m, Ref. + Variant 1b

3.2.2.3 Ratio of LCF to TLCF

Figure 11 shows two different ways to assess potential derailment of wagons.

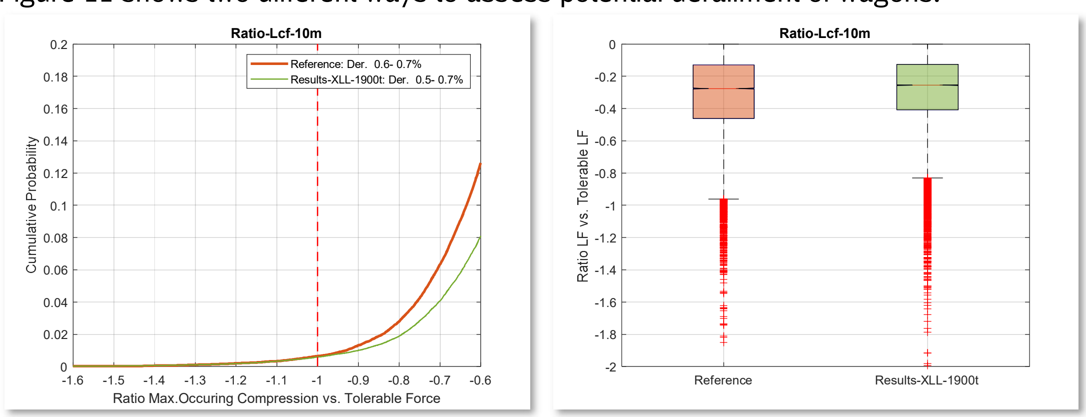

Figure 11: Ratio of Longitudinal Forces within moving distance of 10 m, Ref. + Variant 1b

Especially the boxplot on the right identifies an acceptable level of longitudinal forces as 99.3 % of all coupler forces are showing a higher[10] ratio and thus a lower risk of derailment than the reference.

Figure 12 provides another way of comparing the derailment risk based on quartile plots as explained in section 3.1.3. However, as an exception, the compression ratios in these plots are expressed positive by their absolute value.

[9] size in terms of maximum minus minimum value

[10] Higher values are less critical because compression force ratio is negative.

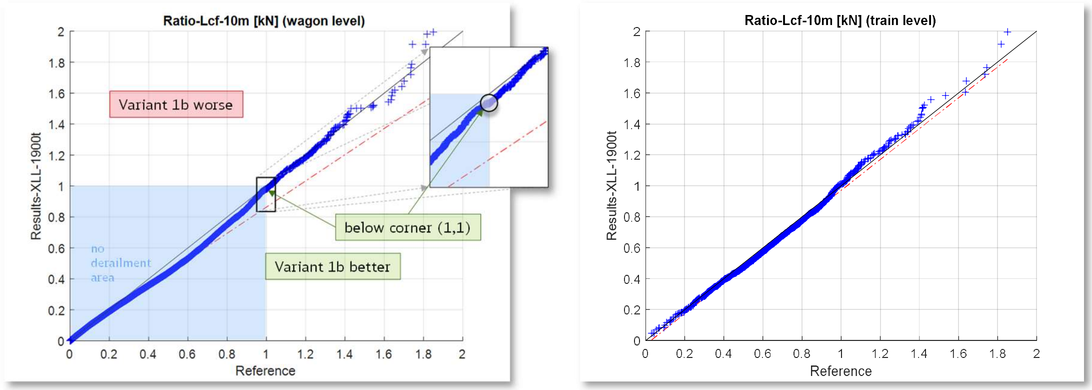

Figure 12: Quartile Plots of Ratio of Longitudinal Forces within 10 m, Ref. + Variant 1b

The quartile plots on wagon level in Figure 12 show, that especially in the “no derailment area” the values of Variant 1b are lower. The curve is leaving this area below the diagonal and that means, that there are less samples in variant 1b entering the critical area of derailment. Up to values of roundabout 1.4 the values are following the diagonal. Above a value of 1.4 the plus-signs, each identifying a single sample, show a random behaviour that does not show an alarming tendency.

The situation on train level is comparable. The general trend, shown by the red dashed line of the linear regression, reveals lower values for variant 1b. In the area of potential derailment (values greater one) the samples show a small increase. That means, that only a small increase of longitudinal forces must be expected. This can be confirmed by having a look to Figure 10 again. The outliers are not extending to an alarming level of compression forces.

3.2.2.4 Assessment of Variant 1b

Significant deviations can be observed for ratios larger than one. Both considerations, the one on wagon level and the one on train level show a lower rate or equal rate of samples that enter the critical area of potential derailment. The deviations in this area are small so that there is no hint that the amount of kinetic and potential energy provoking derailment is significantly increased.

3.3 Emergency brake during traction (T+EB)

3.3.1 Variant 1b, target mass range 1790–1900 t, 1000 samples

3.3.1.1 Description

This manoeuvre is usually the most challenging scenario. However, in a relative approach this hazard is expected to have a low impact on the results because also the reference must deal with this unfavourable situation. There is a complete analogy to the previous case of emergency braking from coasting. Only the manoeuvre is changing. However, it is not the same train family as in section 3.2.

3.3.1.2 Comparison of LCF

Figure 13 compares the distribution of longitudinal compression forces for reference and variant 1b.

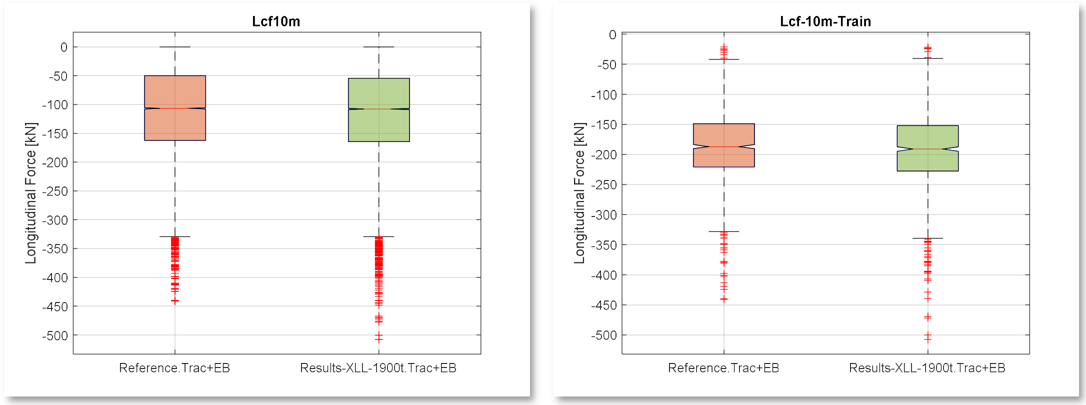

Figure 13: Longitudinal Forces within moving distance of 10 m, Ref. + Variant 1b

The level of forces is very similar for reference and variant 1b. On train level, the reference case shows small differences in terms of a higher median and higher whisker (see boxplots on the right). Furthermore, the variant seems to provide higher compression forces in rare cases with respect to the outliers of the variant's boxplot.

3.3.1.3 Ratio of LCF to TLCF

The results of the manoeuvre in Figure 14 show a comparable behaviour to emergency braking from coasting in section 3.2.

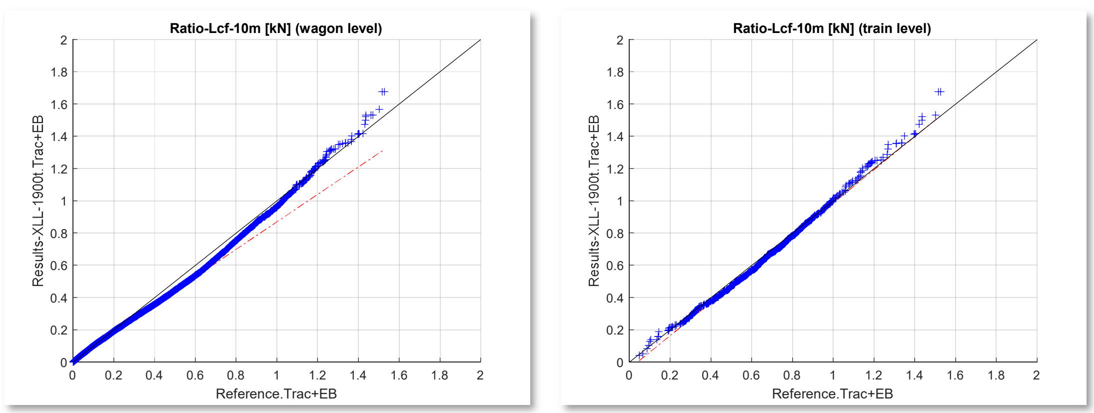

Figure 14: Quartile Plots of Ratio of Longitudinal Forces within 10 m, Ref. + Variant 1b

When the reference enters the derailment area (values greater than 1) the variant does not. So, the variant provides less wagons that enter a critical level of forces.

Considering the potentially derailed wagons it can be observed that variant 1b tends to provide slightly higher ratios. This tendency is not alarming because there are arguments why the operational risk is not significantly increased:

- the deviations from the diagonal are small. There is no hint that kinetic and potential energy of the wagons is increased in a way that different, more severe hazards (compared to the reference) must be faced than those that can be expected for the reference case.

- there is always a random nature on the last points of a distribution showing all their samples
- the extrapolation rules of IRS 40421 [4] for estimating TLCF are considered conservative (s. appendix B section 3.4.2). That means, real values of TLCF are expected to be higher. As there is a cautious linear increase of TLCF depending on the wagon mass it is logical that with increasing LCF due to more mass of the variant the underestimation of TLCF leads to higher values of the variant in terms of the ratio of forces when compared to the reference.

4 Conclusion

The study shows the feasibility of introducing harmonising measures to increase the mass of freight trains when running as P-trains in the network without exclusion of critical wagons, i.e., articulated or permanently coupled wagons, and without increasing the rate of potential derailment or train disruption in an unacceptable way.

The main promising measure is the introduction of a new brake regime XLL that means an extended “Long Locomotive” which adds two more wagons in brake regime G at the front of the train. Instead, shifting critical wagons to favourable positions in the train did not reveal significant benefits when considering substantially higher shunting efforts as well.

Applying the XLL measure to the simulation models increases the maximum of hauled train mass up to 1900 tons without the need to impose additional restrictions regarding minimum mass of wagons, wagon type or wagon sequence.

5 Signatures

Checked and approved:	Created:
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