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Safety assessment of pocket wagons

Safe trailer transport

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Abstract

The use of pocket wagons for transporting semi-trailers has long been a key component of European logistics. The severe accident on the Great Belt Bridge in Denmark in 2019 has sparked discussions on the necessity of stricter safety regulations. This paper examines the current safety standards for semi-trailers on pocket wagons, the implications of the proposed changes to the TSI WAG regulations, and the specific operational conditions on the Great Belt Bridge. Furthermore, it assesses the proportionality of introducing uniform European regulations, considering the differences in infrastructure and operational conditions across the continent.

The semi-trailer transport within continental Europe, where the effects of strong crosswinds are less prevalent, is regarded as safe and operators have implemented safety measures for risk mitigation. Using publicly available data, the probability of a failure occurring was estimated in reference to the Common Safety Method as 1,69 $\cdot 10^{-9}$. The proposed locking force of an 85 kN is found to lack a clear justification. Additionally, the locking force introduces structural and fatigue-related concerns for both the structure and the connection to pocket wagons. Another critical aspect highlighted is that high locking forces could lead to unintended consequences by lifting the wagons while unloading. At present, no market-ready system fully complies with all of the proposed regulations and prevents the application of excessive loads. Given that the proposed changes to the regulations do not address the root causes of past accidents on the Great Belt Bridge, they are found to lack proportionality as a pan-European measure. Instead, a more targeted approach for wagons operating on the Great Belt Bridge, is suggested as a more appropriate solution.

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1. Background

The safety of traffic involving semi-trailers loaded onto pocket wagons is a crucial aspect of intermodal transport in Europe. Ensuring the safety and stability of such transport units is vital for both rail and road infrastructure. Over the years, various regulations and technical standards have been introduced to enhance the safety of these transport systems. For over 50 Years pocket wagons have been traveling through Europe without any significant incidents. Only after a severe accident on the Great Belt Bridge, discussion arose to introduce stricter regulations. But on the other hand, operational conditions on specific infrastructures, such as the Great Belt Bridge in Denmark, differ from those on the European mainland, raising concerns regarding uniform safety standards. This paper discusses the current state of safety for semi-trailers on pocket wagons, the impact of the discussed changes of the TSI WAG [1] regulations, operational conditions on the Great Belt Bridge, and the proportionality of introducing a pan-European regulation.

2. Current Safety of Semi-Trailers on Pocket Wagons

The transportation of semi-trailers on pocket wagons is a widely used intermodal freight method that combines road and rail advantages. To ensure a safe fixation of the semi-trailer on the wagon the king-pin of the semi-trailer is connected to the trailer through a coupling mechanism. However, there have been safety concerns, particularly regarding the secure attachment of empty semi-trailers to the wagons during strong cross winds.

2.1 Risk analysis

The current safety framework provides a high level of safety for this transportation method. Between 2014 and 2023, about 19 million semi-trailers were transported on pocket wagons across Europe [2].

In their investigation report regarding the accident on the Great Belt Bridge in 2019, the Accident Investigation Board Denmark made inquiries to other European accident investigation boards, which had no knowledge of similar incidents [3, p. 150].

Some other incidents involving pocket wagons are mentioned, but they are not directly comparable [3, p. 150 f.]:

- USA: an Amtrak train collided in 1994 with a trailer that had fallen off another train. The wagons are not identical to the ones in the Great Belt Bridge accident.
- Sweden: Double pocket wagons were derailed in 2019 and some of the trailers fell off the wagons while others were still locked in.
- Hamburg: a trailer was not correctly loaded in 2014 and collided with a bridge.
- Norway: a trailer was not correctly loaded in 2006 and collided with a tunnel wall.
- On 28.02.2019, a wagon in a freight train from Germany was stopped in Padborg due to suspicion of a defect in the semi-trailer's attachment. The trailer was skewed due to uneven height adjustment of the support frame.
- On 06.11.2019, a trailer had not been loaded correctly. The king pin was not placed within the support frame. The error was detected at the arrival station.

Apart from loading errors, the only relevant event is the 2019 accident, although the cause cannot be clearly attributed to the coupling mechanism. There was no proof that the king-pin of the involved semi-trailer was inside the locking mechanism and locked correctly. Using data on the annual mileage of the modal split in combined transport from Eurostat [4] and an average speed from the Rail Market Monitoring of the

European Commission [5], the total operating hours between 1990 and 2025 amount to 592.051.458 h. No further historical data is available.

Based on the Common Safety Method (CSM), the frequency of failure is calculated as $1{,}69 \cdot 10^{-9}$. In any case, the occurrence of a failure is to be considered "improbable" (occurrence of failure at a frequency less than or equal to 10^{-7} per operating hour). Considering the limitations of the data basis, an assessment as "highly improbable" (occurrence of failure at a frequency less than or equal to 10^{-9} per operating hour) appears reasonable. This is not an exact risk assessment in terms of the CSM but can be seen as an indicator of the safety level of the existing system. [6]

2.2 Safety measurements

The Great Belt Bridge accident in 2019 underscored the need for more stringent safety measures for such infrastructure. The issues mainly concern the insufficient coupling mechanisms, failure of kingpin fixations or loading mistakes leading to unintended movements under an external force. Furthermore, the investigations could not clearly confirm that the trailer was loaded properly.

There have been investigations of the consequences of the introduction of certain locking forces. The final of the Joint Network Secretariat Normal Procedure Task Force Great Belt Bridge Accident/Incident cites an unpublished analysis by VTG and third party experts report concluding that limiting the force to a maximum of 85 kN will ensure that the wagon itself will not be lifted off the rail [7, p. 115] [7, p. 121]. Lifting the wagon itself when unloading a locked semi-trailer will bring very high force into the support frame and lead to material failure over time. Since there is no current system being able to ensure both a holding force of 85 kN and at the same time ensure the connection will release when the wagon is about to be lifted, it is unclear how to proceed to improve the safety of the system any further. Trying to make the system safer by ensuring a high locking force can lead to uncontrollable high forces in the supporting frame.

Following the two events on the Great Belt Bridge, the accident in 2019 and the incident in 2021, transport operators and regulatory bodies from Denmark have introduced stricter loading protocols, rules for securing devices, and advanced monitoring systems. Aside from that, proposals to amend the WAG TSI were made from DK-NSA and ERA. The impact of these changes is considered below.

3. Impact of the new TSI WAG on safety compared to current standards

The latest revision of the TSI WAG aims to enhance the safety and interoperability of freight wagons across Europe. The following changes are proposed, and their expected impact is added.

Table 1: Comparison of the current standards and the new standards

TSI WAG Requirements	Proposed new standard	Application	Impact
4.2.2.4.1: Strength of the structure	“Devices to secure semi-trailers shall hold semi-trailers in a safe position by withstanding the longitudinal, lateral and vertical downwards directed forces in accordance with the design operating state.”	Does not apply to existing wagons.	A technical solution that can withstand all forces does not exist. The connection to the wagon is at risk in terms of fatigue strength, especially when the trailer is frequently lifted while still attached to the wagon.
4.2.2.4.2: Locking force	“Devices to secure semi-trailers shall lock semi-trailers in a safe position by withstanding the vertical upwards directed forces in accordance with the design operating state.” “Note 1: In absence of a TSI requirement on a minimum crosswind stability for freight wagons $F_{static\ zu}$ shall be 85kN. No additional	Applies retroactively to the existing wagons after 1 year.	The chosen force value is arbitrary and may be too high in the context of vehicle unloading. There is no solution that ensures a minimum holding force of 85 kN and, at the same time, releasing the wagon when a locked semi-trailer is unloaded. Moreover, it is almost impossible to achieve this exact force,

	safety coefficient shall apply." "Note 2: In case a semi-trailer is (unintentionally) lifted during unloading while the king-pin is locked, a force might occur which can lead to damages in the items A. mechanism to lock the king pin, and/or B. the device itself, and/or C. the connection between the device and the unit. Manufacturers shall consider this in the limits and conditions of use of the device they place on the market."		especially when there is also a lateral load. Additionally, lifting a trailer while the kingpin is locked can generate a force exceeding 85 kN, potentially causing lifting of the wagon. It cannot be ruled out that even the neighbouring wagon could be lifted, requiring the structure to withstand these significant forces. Due to the lack of a technical solution, retrofitting is currently not possible.
4.2.2.4.3: Indications of correct loading and securing	"Devices to secure semi-trailers shall indicate reliably if the king-pin of the semi-trailer is correctly positioned and the semi-trailer is correctly locked. The correct position of the king-pin of the semi-trailer and the locking of	Does not apply to existing wagons.	No current reliable solution which shows correct loading and securing in conformity with the new standards, "reliably" is not defined.

	the semi-trailer shall be detected independently. The indication shall be visible for the loading and checking staff in any loading situation of the unit.”		
4.2.2.4.4: Marking with information regarding these devices	“The unit shall have on both sides a marking related to the device to secure semi-trailers on both sides for each device to secure semi-trailers, which contains: - All information relevant for the safe use of the devices to secure semi-trailers by loading and checking staff; - The compliance with point 4.2.2.4.2.”	Applies retroactively to the existing wagons after 1 year.	It remains unclear, why the marking of the maintenance interval and dates are necessary as appendix II of EU regulation 2019/779 [8] assigns responsibility to the entity in charge of maintenance to have “a procedure to send vehicles for maintenance in due time” and “to have a procedure to manage the removal of vehicles from operation for maintenance or when safe operation is impaired”. Updating markings at fixed intervals, despite the existence of digital solutions, involves significant effort with questionable informational value.

The implementation of these standards requires significant investment, administrative effort from operators, without the guarantee to fulfill the new technical requirements and without gaining safety.

4. Operational conditions on the Great Belt Bridge compared to continental Europe

The Great Belt Bridge in Denmark presents unique operational challenges for rail freight compared to mainland Europe. In contrast, rail routes in continental Europe typically offer more sheltered conditions, with fewer extreme wind influences and more diversified routing options. However, there are a few infrastructure examples predestined for a lot of wind listed below without a claim to completeness:

- Line between Perpignan und Luxembourg
- Third Moerdijk bridge
- Fehmarnsund bridge (no train service since 2022 due to reconstruction)
- Öresund bridge
- Rhine Valley Railway
- Trieste line

At this point, there are no known accidents on the mentioned infrastructures. On the one hand, this is due to the extensive safety measures taken by the operators. These mainly include close monitoring of wind speeds, operational risk mitigation such as reducing train speed or temporarily halting traffic, and infrastructure measures like wind fences. On the other hand, all of the aforementioned locations have a less critical susceptibility to critical wind situations.

The Joint Network Secretariat Normal Procedure Task Force Great Belt Bridge Accident/Incident write in their final report [7, p. 74]:

"It cannot be agreed that the GBB is not a special location in the European network, as its exceptional length increases substantially the time of exposure of trains; these are not treated through probable scenarios considering wind directions, wind speeds, wind gusts, etc. (risks exposure)."

The Danish Technical University and BaneDanmark published a report on wind on the Great Belt Bridge in July 2021 [9]. They performed static test for the loading cases king-pin locked in the structure, king-pin not locked but within the structure, king-pin unlocked behind the structure and king-pin unlocked in front of the structure.

The report concluded that above windspeeds of 34,9 m/s at train speeds of 120 km/h, there is a risk that an empty trailer on a pocket wagon turns over or derails. However, they stated that if the hitch is not locked within the structure, it can be blown out of gauge at windspeeds as low as 19 m/s [7, p. 76].

DB Systemtechnik performed a detailed simulation of the aerodynamics to obtain the resulting forces on locking mechanism during 10 s gust wind. The results are shown in figure 1. [7, p. 115f]

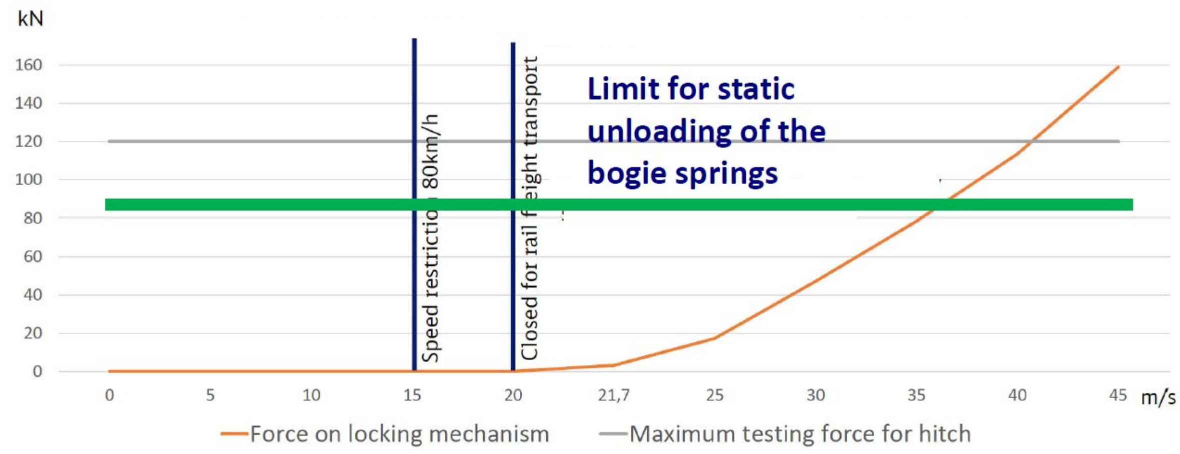

Figure 1: Resulting force on the locking mechanism depending on windspeed applicable for all hitch types in use [7, p. 115]

The forces resulting from the wind show a sufficient locking within the operational restrictions of 20 m/s [7, p. 116]. This is contradicting the tests by the Danish Technical University. The methodology of the tests of the Danish Technical University is not described in enough detail to assess their accuracy. It is unclear what condition the structure was in, how often the tests were repeated, what vertical locking force can be assumed and how the lateral force was applied. A linear increase in force contradicts the real conditions during a gust and allows component movements that, in reality, would more likely have led to jamming within the structure.

On the Great Belt bridge, there are wind restrictions using ten minutes mean value in place that limits the speed of freight traffic to 80 km/h at windspeeds of 15 m/s and stops cargo traffic at 20 m/s. It must be assumed that the wind gusts that occur are significantly higher than the limit values. Using a mean value ignores the influence of gusts.

The infrastructure operator BaneDanmark identified three factors in their risk analysis of the infrastructure, that could occur on other European Infrastructure [7, p. 78]: Firstly, there are no European requirements for locking force yet, secondly there are no restrictions on transport of empty trailers and lastly the wind restrictions in Europe are above the threshold where an empty trailer with no vertical locking force can be blown out of gauge. [7, p. 78]

BaneDanmark neither provides substantiated evidence for the magnitude of force it deems necessary, nor are the underlying investigations on which this assertion is based documented in a scientifically robust and transparent manner. Moreover, the lack of methodological detail prevents independent reproducibility, which would be essential for informed public and scientific discourse. Consequently, the proposed restriction on locking force and trailer weight must be critically reassessed.

If comparable environmental conditions existed throughout Europe and exceeded the proposed thresholds, it remains unclear why safety-related incidents are reported almost exclusively in Denmark—particularly on the Great Belt Bridge. The assertion that such conditions are widespread across Europe lacks plausibility and empirical support.

This evident deficiency in scientific rigor appears to be tolerated in order to deflect from considering infrastructure-related mitigation strategies. The absence of any meaningful examination of potential countermeasures such as the installation of wind protection barriers, which have been implemented on other exposed structures like the Third Moerdijk Bridge, remains unaccounted for. This suggests a general reluctance on the part of BaneDanmark to pursue infrastructure-based interventions that could substantially enhance operational safety.

5. Proportionality of introducing a Pan-European regulation

The concept of proportionality is fundamental in regulatory frameworks, ensuring that any new measures are appropriate and not excessively burdensome relative to the issues they aim to address. In the context of introducing a pan-European regulation for transporting semi-trailers on pocket wagons, it is essential to assess whether such regulation is justified and balanced. The basic idea of the Technical Specifications for Interoperability is to ensure a harmonization of standards with a reduction of inconsistencies and potential safety gaps arising from varying national regulations, a facilitation of cross-border transport and an enhancement of safety and thereby bolstering public confidence in rail freight safety. With great regulating power comes a great responsibility to be aware of the consequences of the technical regulations. Multiple concerns can and have been raised within this paper:

- The traffic within continental Europe without strong crosswinds can be assumed as safe and the risk regarding a trailer moving outside the gauge during transport can be considered under control.
- The main problem is not the exact value of a locking force but rather the semitrailer not being properly loaded. The analysis of the Danish Technical University shows that if a trailer is not securely fastened, freight traffic must be stopped at wind speeds below 14.2 m/s to avoid the risk of it blowing off, while the wind limit can be set up to 26.1 m/s if trailers are properly secured [9, p. 5]. Still, there are several open questions regarding the testing methodology that call into question the unrestricted use of the findings presented there and require further investigations.
- It is still undefined, what “locking reliable” means. Without this, a risk assessment is impossible.
- There is no reason to define the locking force limit at exactly 85 kN regarding the management of the suggested risk of lifting the trailer out of the lock or overturning the trailer.
- A higher locking force results in a higher needed strength of the structure. This has been considered. What has not been considered are both the structural requirements of the structure and especially fatigue strength of both structure and wagon. Those risks are significant and have not been managed.

- The locking force comes with two further side effects. Firstly, it allows the lifting of wagon itself. It must be assumed that standard procedure in that case will be disregarded unofficially. Secondly, the effects of lifting one waggon towards the neighbouring waggon are unclear and carry significant risk.
- There is no system ready for market that fully fulfills the proposed regulations. The long-term consequences of retrofitting to an unfinished solution cannot be assessed.
- It is to be expected that the proposed changes will remove the legacy protection, forcing retrofitting activities.
- A possible new approval after retrofitting may be required, with the risk that the converted vehicles might not be approved.
- The use of specific regulations for a specific infrastructure has proven successful. Prime example is the German ban on tunnel encounters forcing certain operation rules into action to avoid risks from specific cases of the usage of the infrastructure.
- Lastly, the economic burden will prove disproportionately to safety gains for both existing and new units, if the change proposal is accepted.

The proposed changes defy the above stated purpose of TSIs. It is strongly suggested to consider a local solution for this very specific problem. The proposed changes do not solve the reasons for the two events on the Great-Belt-Bridge and thereby cannot be deemed proportional as a Pan-European regulation.

6. Conclusion

Ensuring the safety of semi-trailers transported on pocket wagons remains a top priority for European freight transport. A harmonized approach to regulation can enhance safety and efficiency, but careful consideration is required to ensure that new rules are proportionate, technically analyzed and feasible and economically viable for all stakeholders involved. Ultimately, a balanced approach that incorporates regional specificities while promoting overall safety standards is key to advancing the future of intermodal freight transport in Europe.

It must be concluded that simply defining 85 kN is premature and not reasonable for all of Europe. It is strongly suggested to consider only a solution for the Great Belt Bridge instead of changing the TSI WAG without fully grasping the consequences and perform an independent, detailed technical risk analysis.

References

[1] European Union, „Regulation (EU) 2020/387 of the Commission of 10 March 2020 amending Regulation (EU) No. 321/2013 regarding the technical specifications for interoperability of the ‘Wagons’ subsystem,“ 2013.

[2] eurostat, European Union Directorate-General for Communication, [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/rail_go_itu/default/table?lang=de&category=rail.rail_go. [Zugriff am 3 März 2025].

[3] Accident Investigation Board Denmark, „Undersøgelsesrapport. Lyntog L 210 kollideret med sættevognstrailer fra godstog G 9233 på Storebæltsbroen (Vestbroen),“ Havarikommissionen, 2019.

[4] European Union, „Goods and passenger train traffic performance,“ [Online]. Available: https://ec.europa.eu/eurostat/databrowser/view/rail_tf_trainmv/default/table?category=rail.rail_tf. [Zugriff am 01 04 2025].

[5] European Commission, „Eighth monitoring report on the development of the rail market under Article 15(4) of Directive 2012/34/EU of the European Parliament and of the Council,“ 2023.

[6] European Commission, „Commission Implementing Regulation (EU) No 402/2 of 30 April 2013 on the common safety method for risk evaluation and assessment,“ 2013.

[7] JNS Normal Procedure Task Force, „Great Belt bridge Accident/Incident Final report,“ Joint Network Secretariat, 2022.

[8] European Union, „Commission Implementing Regulation (EU) 2019/779 of 16 May 2019 laying down detailed provisions on a system of certification of entities in charge of maintenance of vehicles pursuant to Directive (EU) 2016/798 of the European Parliament and of the Council,“ 2019.

[9] Danish Technical University und banedanmark, „Analyse af vindrestriktioner på Storebæltsforbindelsen,“ 2021.

[10] M. van Leijen, „RailFreight.com,“ ProMedia Group, [Online]. Available: https://www.railfreight.com/policy/2019/02/12/ban-on-pocketwagons-lead-to-cost-increase-european-rail-freight/. [Zugriff am 12 02 2025].