REQUIREMENTS ON COUPLING STRENGTH OF B-TRIPLE AND TRUCK B-DOUBLE COMBINATIONS




Bruno Augusto
MSc in Mechanical engineering from Technical University of Lisbon (IST), 2009. Working as research engineer at vehicle systems and driving simulation unit at Swedish National Road and Transport Research Institute (VTI).

Sogol Kharrazi
PhD in Machine and Vehicle Systems from Chalmers University of Technology. Working as senior researcher at Swedish National Road and Transport Research Institute (VTI), and as adjunct associate professor at Linköping University.

Fredrik Bruzelius
PhD in Control theory from Chalmers University of Technology. Working as senior researcher at Swedish National Road and Transport Research Institute (VTI), and as adjunct professor at Chalmers University of Technology.

Bolennarth Svensson
M.Sc. from Chalmers University of Technology, Sweden, 1973 and Ph.D. from University of Strathclyde, Scotland, 1998. Former VBG Truck Equipment employee.

Abstract

A failure in the coupling of an articulated vehicle could potentially have a devastating effect if it occurs while driving. To prevent this from happening, states and road authorities impose requirements in terms of tolerated forces on couplings in an articulated vehicle. These requirements are unique for each vehicle configuration and need to be formulated before allowing a new vehicle configuration on public roads. This work proposes requirements for two configurations: B-triple (tractor-link trailer-link trailer-semitrailer) and Truck-B-double (truck-dolly-link trailer-semitrailer), that are not currently covered in the ISO 18688:2013 standard (ISO standard). Simulations were performed to calculate joint forces, for the B-triple, Truck-B-double and similar vehicles that are covered in the ISO standard. The proposed and existing requirements were compared with simulation results, showing that the proposals arising from this work are in line with what is observed for the articulated vehicles currently included in the ISO standard.

Keywords: Coupling forces, D-value, V-value, B-triple, Truck-B-double, ISO 18688:2013

1. Introduction

The forces in the couplings of articulated vehicle combinations, propel and fully determine the path of any towed unit, thus playing a significant role in the vehicle behavior. A failure in a coupling could potentially have a devastating effect if it occurs while driving. To prevent this from happening, road authorities impose requirements in terms of tolerated forces on any coupling selection.

Requirements for the coupling arrangements are stated in terms of maximum forces in the directions more susceptible to failure. For fifth wheel arrangements, this implies the longitudinal direction, while in the case of a clevis coupling on a drawbar attached to a center axle trailer, requirements are stated in both longitudinal and vertical directions.

Testing a coupling for compliance with specifications is achieved by exposing it to repeated (sinusoidal) forces in a test rig, with an amplitude described by the rating of the coupling. This makes the requirement a mixture between safety margins and fatigue. Further details can be found in ISO 8718:2001, as well as in the regulation UNECE R55. The challenge lies with identifying the amplitude of the rating forces.

The coupling ratings should comfortably cover expectable driving conditions, while not being oversized, thus minimizing extra weight as well as usage of material and resources. Hence, determining a rating that is “just right” depends on the use case for the coupling. The problem at hand lies in finding an appropriate dimensioning case representing driving situations that would lead to high force amplitudes at the coupling. This dimensioning case should be connected to the real usage of the vehicle, but still, also give enough margin for potential unknown situations and loads.

Once a dimensioning case is defined, determining the force levels at the joints is far from trivial. Field tests are too expensive and usually complicated to perform. References to such measurements are scarce in the literature related to coupling forces, see (Svensson et. al. (2016)) and (Sweatman (1980)). In the absence of such measurements, expressions to derive coupling forces and their respective ratings, are a necessity.

Just like in the dimensioning case, a balance needs to be struck between complexity and simplicity of expressions to compute maximum force amplitude at a joint. From a practical perspective, such expressions need to be simple and understandable and depend on quantities that can be readily measured, estimated, or available from a supplier. From an accuracy point of view, the expressions need to be complex enough to incorporate the main phenomena that contribute to the maximum force. This balance is non-trivial and may sometimes be governed by non-factual opinions rather than well-grounded evidence.

Existing expressions have been developed primarily by Sweatman, in Australia, in the eighties, see (Sweatman (1980)) and (Sweatman (1987)). In this work, the dimensioning case is given by starting form standstill situation. The driving torque of the propelled lead vehicle in a vehicle combination is generating a propelling force that is propagated throughout the combination via the couplings. Sweatman derives equations for a steady state as well as for dynamic situations and compares these with field measurements. Finally, he derives simplified equations based on measurements and analytical expressions. These simplified equations are the basis for the existing ISO standard that in turn is the source for the Swedish regulations.

The equations in the ISO standard are derived for five different vehicle combinations. This report aims to extend this set of equations to new vehicle combinations, not currently covered, which can potentially become legal on the Swedish road network: The B-triple (Tractor + Link trailer + Link trailer + semitrailer) and the Truck-B-double (Rigid truck + converter dolly + Link trailer + semitrailer) combinations. Allowing longer and heavier combinations on the road network is part of a larger strategy in Sweden (and many other countries) to increase transport efficiency, see for example the work in the Performance Based Standards project, Kharrazi et. al. (2017).

2. ISO 18688:2013 – Coupling Strength Requirements

ISO 18688 was released in 2013 under the title *Commercial road vehicles – Coupling equipment between vehicles in multiple vehicle combinations – Strength requirements*. This standard provides dimensioning guidelines for the couplings of long combinations of vehicles, focusing on two coupling types, 5th wheel and drawbar.

The forces generated in the coupling between two vehicles are dependent on the coupling type, the mass of the vehicles and the external forces the vehicles are subjected to. This makes it impossible to dimension the couplings independently of their use cases, implying that the dimensioning requirements are computed on a use case basis; a use case being herein represented as a vehicle combination. Taking this approach, the ISO standard provides strength requirements for the joints in five different vehicle combinations, see Table 1.

Table 1 - ISO18688:2013 Covered Vehicle Combinations

ISO Name	Constituent units	Joint types
ISO Vehicle combination 1	truck + dolly + semitrailer* (**Nordic combination**)	Drawbar, 5th wheel
ISO Vehicle combination 2	tractor + semitrailer*+ centre-axle trailer	5th wheel, drawbar
ISO Vehicle combination 3	tractor + semitrailer*+ dolly + semitrailer* (**A-double**)	5th wheel, drawbar, 5th wheel
ISO Vehicle combination 4	truck + centre-axle trailer + centre-axle trailer	Drawbar, drawbar
ISO Vehicle combination 5	tractor + link trailer + semitrailer (**B-double****)	5th wheel, 5th wheel

* It is referred to as A-semi in the ISO standard ** It is referred to as B-train in the ISO standard

The strength requirements given by the ISO standard cover longitudinal forces on the joint, D values, as well as vertical forces on the joint, V values. Both V and D values are computed using a combination of empiric observations and simple expressions which govern the vehicle dynamics. It should be noted that the minimum performance capability required at each coupling point, i.e. V & D values, shall be calculated individually. But the highest performance capability value determined for each type of coupling shall apply throughout the whole vehicle combination.

2.1 Background on D Value

The D value is a rating used to specify the maximum longitudinal force that a coupling in a vehicle combination should withstand. This D-value is historically computed according to a simple assumption between two vehicles under the case that the propelling lead vehicle is accelerating. Consider the truck and trailer in Figure 1.

In steady state, assuming both truck and trailer are travelling with a constant longitudinal acceleration $a_x = g$, then the force at the joint can be represented as:

$$F_D = \frac{M_1 M_2}{M_1 + M_2} g = \frac{AB}{A + B} g \tag{1}$$

In Equation (1) the maximum acceleration of g is considered, which is only feasible if the whole vehicle mass is on driven axles. Furthermore, the equation does not include transient forces which occur when the acceleration is changed. These forces are mainly due to the compliance of the couplings and due to the pitch motion of the involved vehicles. In Sweatman (March 1980) expressions are derived to account for typical accelerations and compliances, using a combination of analytical and empirical relations. These expressions are further developed in Sweatman (1987) and fitted to the D value calculations found in the ISO standard.

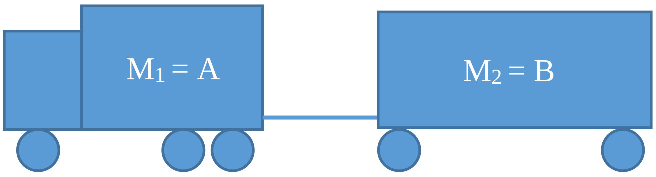

Figure 1 – Simple truck and trailer

The D value calculations given in the ISO standard are a combination of Equation (1), adjustments to account for its conservative nature (pure gains), and modifications to account for the magnitude of transient forces, Sweatman (1980) and Sweatman(1987). All D values are calculated on a vehicle combination basis.

2.2 Background for V Value

According to the ISO standard, the V value is determined only for drawbar couplings. This is motivated by the fact that the other joint type, i.e. fifth wheel, is designed to sustain vertical loads and have some vertical compliance, whereas a clevis coupling is comparatively rigid in both longitudinal and vertical directions.

3. Extension of the ISO18688:2013 Requirements

The strength requirement on a given coupling is a function of the load case. Hence, vehicle combinations which are not covered by the existing standard are lacking an important metric when it comes to evaluation of roadworthiness. This work focuses on expansion of the standard requirements for two vehicles which are currently not covered by the ISO standard, but are deemed of relevance for the Swedish transportation system.

3.1 B-Triple

The B-triple consists of a tractor pulling a link trailer, followed by another link trailer and finally a semi-trailer. In this vehicle combination all three couplings are made with a fifth wheel. These are attached to the tractor and the two proceeding link trailers, see Figure 2.

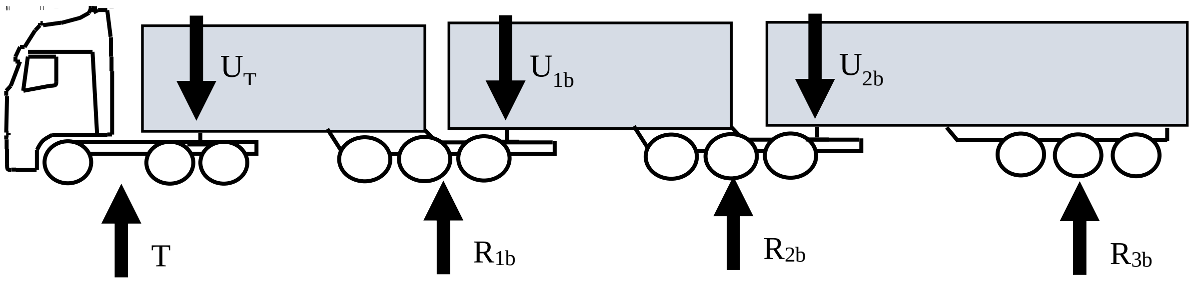

Figure 2 - A B-triple combination or TR6x4_LT3_LT3_ST3.

The quantities depicted in Figure 2 are harmonized with the nomenclature used in the ISO standard. The masses of the individual elements of the vehicle combination are not used, and instead the axle weights (gross weights) are represented since they are easy to measure. Formally, these are forces, but to respect the nomenclature, they are represented by the corresponding masses that would result in these forces. Additionally, the gross weight of the tractor (T), the gross axle loads on the trailer (R_{1b}, R_{2b}, and R_{3b}), the load from the trailers to the fifth the wheel (U_T, U_{1b} , and U_{2b}) are also depicted in **Error! Reference source not found.**.

D and V values

The derivation of D and V values is made in alignment with how these values are derived for the currently covered vehicles in the ISO standard. The basis for the D value is Equation (1).

The B-triple is formed with only one type of coupling, the fifth wheel. The ISO standard includes a similar combination, but with one less unit, namely B-double. In the ISO standard it is assumed that the front most coupling will take the highest load when the tractor starts to propel the vehicle combination, thus the first coupling is used to set the requirement for all couplings in the combination. This approach can be fine for a B-double, since the provided formula results in similar D-values for both couplings, considering the load proportions in either side of the couplings in a fully loaded vehicle. However, that is not true for a B-triple. Therefore, here the relevant formula is provided for all the three couplings. Note that as stated earlier, the D-values shall be calculated for each fifth wheel, but the highest value shall apply throughout the whole vehicle combination.

For the tractor fifth wheel, let A in Equation (1) be represented by the gross load of the tractor, $A = T$, and B be represented by the sum of the trailers' weights, $B = R_{1b} + R_{2b} + R_{3b} + U_T$. Replacing these quantities directly in Equation (1) would yield what is here called the raw D value, D_{raw}. This D_{raw} needs to be adjusted, in line with the modifications made for similar vehicle combinations in the ISO standard:

1. Total mass is $A + B - U_T$, since the term U_T is counted twice as it is included in both A, as a part of T, and B. U_T is thus removed from the denominator, in line with what is done with the currently covered vehicle combinations in the ISO standard.
2. In the numerator, A is replaced by $A + 0.08B$ to account for transient effects. This is based on empirical observations, see Sweatman (1987).
3. A gain of 0.5 is used to account for typical acceleration levels. This is also based on empirical observations, see Sweatman (1987).

Similarly, the D value equation for the other couplings of the B-triple can be derived, see Table 2. Note that a conservative approach is taken and the factor 0.08, which is included to account for the transient effects, is multiplied by the larger mass on each side of each coupling.

V values are not considered for fifth wheels and since the B-Triple only consists of fifth wheel couplings, no V values are defined for this vehicle combination.

Table 2 – B-Triple (TR6x4_LT3_LT3_ST3) D Value. See Figure 2 for the meaning of the different variables.

Joint	*A*	*B*	*D*
Fifth Wheel Tractor	T	$R_{1b} + R_{2b} + R_{3b} + U_T$	$0.5g\dfrac{B(A + 0.08B)}{A + B - U_T}$
Fifth Wheel 1st Link trailer	$\mathrm{T} + R_{1b}$	$R_{2b} + R_{3b} + U_{1\mathrm{b}}$	$0.5g\dfrac{B(A + 0.08B)}{A + B - U_{1\mathrm{b}}}$
Fifth Wheel 2nd Link trailer	$\mathrm{T} + R_{1b} + R_{2b}$	$R_{3b} + U_{2\mathrm{b}}$	$0.5g\dfrac{A(B + 0.08A)}{A + B - U_{2\mathrm{b}}}$

3.2 Truck-B-double

The Truck-B-double combination consists of a rigid truck, a converter dolly, a link trailer and a semi-trailer, see Figure 3. The combination name Truck-B-double is not established elsewhere and is a mix of terms to describe the involved vehicles. The three couplings are the fifth wheel on the dolly, a fifth wheel in the link trailer, and a drawbar connecting the truck and the dolly, without a hinge, and connected to a clevis coupling.

Just like for the B-Triple, the nomenclature used on Truck-B-Double, Figure 3 , is harmonized with the ISO standard's nomenclature. The gross weight of the truck (T) is depicted, as well as the loads on the axle groups (C_d, R_{1b}, and R_{2b}), and the loads on the fifth wheels (U_T, U_{1b}). Also, the length of the dolly converter (L) is given and is measured as the distance between the coupling eye and the coupling point on the fifth wheel of the converter dolly.

D and V Values

The derivation of D and V values is made in alignment with how these values are derived for the currently covered vehicles in the ISO standard. The basis for the D value is Equation (1).

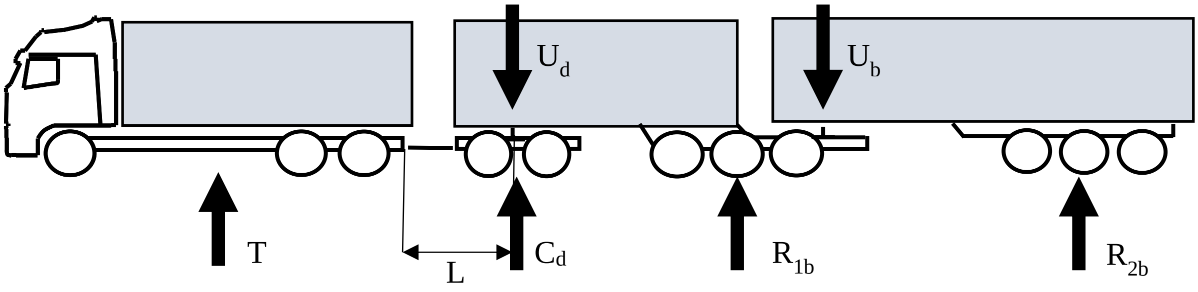

Figure 3 - A Truck-B-Double combination or TK6x4_DY2_LT3_ST3

The Truck-B-Double consists of two fifth wheel couplings and a draw bar coupling from the converter dolly to the truck. Computation of the D and V values for the fifth wheels couplings follows the same reasoning as in the B-Triple case, so those explanations will be skipped here.

The V values are only computed for the drawbar connection between the dolly converter and its towing vehicle. In the ISO standard, the expression for the drawbar vertical force at the coupling point is a function of the length L, see Figure 3, and the load the dolly is exposed to. This means the expressions existing in the ISO standard can be reused for this case without modifications.

Following the examples given in the ISO standard, the D value for the drawbar is calculated by scaling Equation (1) with 0.9, where $A = T$ and $B = C_d + R_{1b} + R_{2b}$.

The D and V values for all the joints in the Truck-B-Double are given in Table 3. W_d is the dolly tare mass, $W_d = C_d - U_d$.

Table 3 – Truck-B-Double (TK6x4_DY2_LT3_ST3) D and V values. See Figure 3 for the meaning of the different variables.

Joint	*A*	*B*	*D*	*V*
Drawbar	T	$C_d + R_{1b} + R_{2b}$	$0.9g\dfrac{AB}{A+B}$	$\max\left(\dfrac{54}{L}, 5\dfrac{C_d}{L}\right)$
Fifth Wheel Dolly	$T + W_d$	$U_d + R_{1b} + R_{2b}$	$0.5g\dfrac{B(A + 0.08B)}{A+B-U_d}$	NA
Fifth Wheel Link trailer	$T + C_d + R_{1b}$	$U_b + R_{2b}$	$0.5g\dfrac{A(B + 0.08A)}{A+B-U_b}$	NA

4. Alignment of Proposed Metrics with Current Metrics in ISO 18868:2013

The expression proposed in this report need to be scrutinized to understand how they compare to those in the ISO standard. This is achieved through simulations of the newly considered vehicles as well as those which are covered in the ISO standard.

4.1 Comparison Test Case

The basis for the D value formulas is given by Equation (1). These formulas were designed assuming that one mass pulls another coupled mass, with as much force as allowed by the surface grip. Hence, the simulations where designed such that they would come as close as possible to the idealized case.

In this study, all vehicles were simulated in the same circumstances. The friction coefficient on the road was set to roughly 0.75, which could be considered to represent normal dry friction on a road surface, see Kharrazi et. al. (2017). The first vehicle in the combination was then made to accelerate with 40% of the maximum available force considering the load on the driven axles and the road friction. The simulation was terminated once all vehicles in the combination were traveling with the same acceleration, a steady state where the jerk is zero for all units. Once the simulation is complete, the joint (coupling) sensors are polled for the maximum amplitude of the observed forces, per axis, for the entirety of the test duration. This data is then used for analysis and comparison with the ISO standard requirements.

The choice to use 40% of the available propulsion force for each axle, is motivated in Sweatman (1980). It is claimed that this is a realistic boundary on the range of forces a truck could be expected to use in real driving conditions. This strengthens the case for a comparison between the outputs of the simulation and their real-world counterparts.

4.2 Simulated Vehicles

Not all vehicles covered by the ISO standard were simulated. Since the B-Triple and the Truck-B-Double do not have central axle trailers, those combinations in the ISO standard which contain central axle trailers, were skipped.

The vehicles modelled and simulated in this study are depicted in Table 4. All vehicles are loaded to maximum and according to the principle of a uniform load distributed across the first 80% of the length of the vehicle. For further details and descriptions of models, refer to Kharrazi et. al. (2017), and the PBS projects.

Table 4 – Simulated Vehicles and their Properties

Vehicle name	ISO	Constituent units	Joint types	Weight
TK6x4_DY2_ST3 (Nordic combination)	No. 1	Truck + dolly + semitrailer	Drawbar, 5^{th} wheel	64 t
TR6x4_ST3_DY2_ST3 (A-double)	No. 3	Tractor + semitrailer + dolly + semitrailer	5^{th} wheel, drawbar, 5^{th} wheel	80 t
TR6x4_LT3_ST3 (B-double)	No. 5	Tractor + link trailer + semitrailer A-semi	5^{th} wheel, 5^{th} wheel	74 t
TK6x4_DY2_LT3_ST3 (Truck-B-double)	New	Truck+ dolly + link trailer + semitrailer	Drawbar, 5^{th} wheel, 5^{th} wheel	92 t
TR6x4_LT3_LT3_ST3 (B-triple)	New	Tractor + link trailer + link trailer + semitrailer	5^{th} wheel, 5^{th} wheel, 5^{th} wheel	98 t

4.3 D Values Results

The results of the simulations are presented in Figure 4.

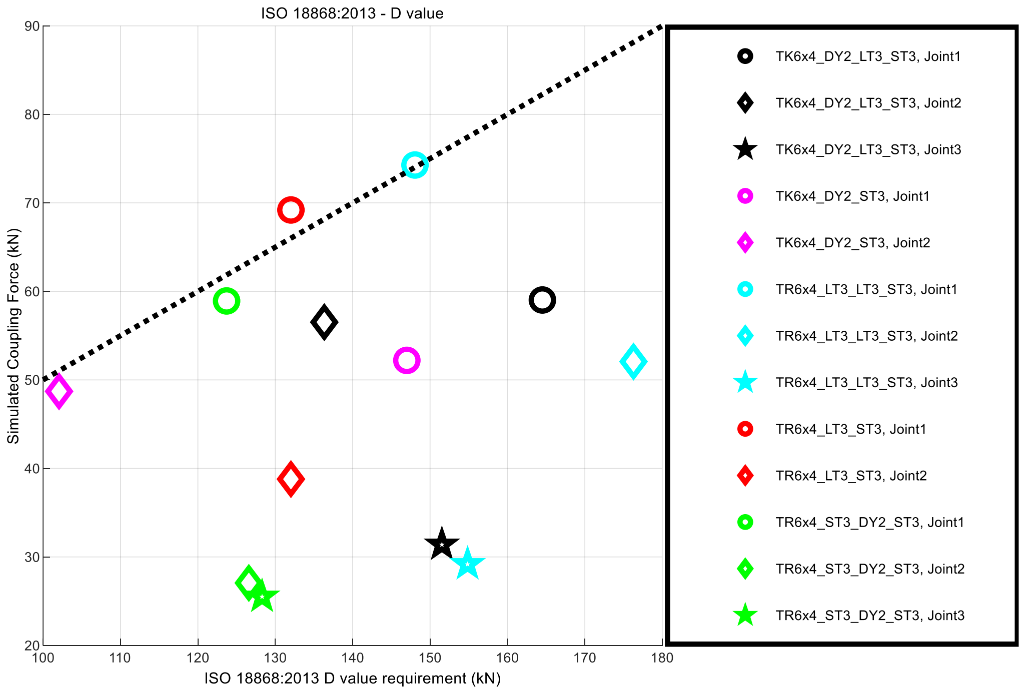

Figure 4 – Simulated joint longitudinal force versus D value requirements from ISO 18868:2013. Each vehicle combination has its own color. Circle - first joint / Diamond - second joint / Star - third joint. Dotted line has a slope of 0.5.

Interpretation of Figure 4 cannot be detached from the type of joint under analysis as well as how the combination weight is distributed ahead and behind said joint. Given these conditions, a fair comparison can only be performed between the first joint of combinations with the same first unit, i.e. same first joint type. In these circumstances, it is possible to draw conclusions on the relationship between coupling forces in distinct vehicle combinations, based only on the differences in total vehicle combination weight.

For the remaining joints, a weaker comparison can be attempted between vehicles with the same first unit if the weight distribution ahead and behind the regarded joint is similar. This is hardly the case for the simulated vehicle combinations but could be accepted for the same joint positions if the vehicle combinations have similar total mass.

Truck Led Combinations

Taking the case of the combinations led by a truck, pink (Nordic combination) and black (Truck-B-double) markers, the vehicle combination with the higher mass, Truck-B-double, shows higher D values than its counterpart. This is easily recognized since the black markers are further to the right than pink markers of the same shape, i.e. same joint id. This is in line with the expectation that the same truck, driving a heavier load with the same propulsion force needs to experience higher coupling forces, c.f. equation (1). The simulations confirm this and the increase of D-values shows that the updated requirements given by this report are adequate and aligned with the existing standard.

Tractor Led Combinations

Led by a tractor are the red vehicle combination (B-double) with a total mass of 74 tons, the green vehicle combination (A-double) with a total mass of 80 tons, and the blue vehicle combination (B-triple) with a total mass of 98 tons. The blue vehicle combination, B-triple, is not covered by the ISO 18688:2013 standard and its estimation of D-values was made with the equations proposed in this report.

Assuming that the mass difference is bigger than the difference in propulsion forces (minimized by using the same tractor in all combinations) one can see that the B-triple, blue vehicle combination, presents higher coupling forces than its counterparts and that the estimation of the D value is consequently higher. This shows that the proposed formula for D value estimation of the B-triple is in line with what is currently seen in the standard, for the existing vehicles.

Remarks

Most simulated joint forces are less than half of the requirement values set by the ISO standard. This is easily verified by confirming that almost all points are found bellow the dotted black line in Figure 4, which has a slope of 0.5.

While applying the standard requirements, a trend was identified in the relationship between D-value requirements for couplings with a 5th wheel and couplings with a drawbar: for a similar position in the unit, or a similar weight distribution before and after the joint, the 5th wheel shows lower requirements than the drawbar. A simple example of this problem is illustrated by the Truck-B-double, the black vehicle combination. The difference between the simulated forces (distance in the vertical axis) for joint 1 (circle) and joint 2 (diamond) is not large. This is expected because the towed mass before and after the dolly is very similar due to the low mass of the dolly, and thus the coupling forces are similar in magnitude. However, the difference in ISO D values for the first and second joint, is quite large in comparison to the difference between the simulated values. It appears that the 5th wheel requirements do not seem to be scaled in the same way as the drawbar requirements. A potential explanation may be found on how the standard compensates for transient forces which may have a higher amplitude than those encountered in a stationary regime. If certain joint types are more susceptible to these transient than others, possibly due to the mechanisms involved, then it would be reasonable to assume that this is reflected in the outputs of the equations proposed by the standard.

4.4 V Values Results

Table 5 depicts the maximum vertical force at the drawbar couplings and the corresponding V-values.

Table 5 – Simulated vertical force at coupling and V value from ISO 18688:2013.

Vehicle	Joint No.	Coupling Force (kN)	% of V value	V value (kN)
Nordic combination	1	8.13	25.14	32.34
A-double	2	3.926	11.92	32.73
Truck-B-double	1	9.256	25.89	35.75

The equations for V-values are only dependent on drawbar length and the load on the axles of the dolly. When taking the same drawbar length for all vehicles the load on the dolly axles is the determining factor for the V value. Having more weight on the dolly axles, the Truck-B-Double naturally produces higher V values. When looking at the simulated force values, it is possible to see that the Truck-B-Double vehicle also generates higher vertical forces on the joint than the other two vehicles. This shows that the requirement is computed in line with the magnitude of the forces expected in the new vehicle.

5. Discussion

Forces occurring in a coupling are characterized by different amplitudes and bandwidth, depending on the nature of the stimulus the vehicle is exposed to. Three general types of stimuli can be identified:

1. Lateral and longitudinal forces due to steering, braking, and accelerating.
2. Road borne disturbances.
3. Park and switchyard driving.

The first category includes the normal operation due to the road planar motion of the vehicle combination. During braking and close to standstill, when the suspension dissipates the energy of the braking force, transient pitch motion between units can create extreme loads on the joints. This can be particularly extreme in the case of a clevis coupling given its high stiffness in the vertical and longitudinal dimensions. Additionally, the braking distribution along a combination will have big impact on the joint forces, since differences in initial deceleration between vehicles will be evened out by the forces transmitted through the joints. A normative case should not rely on specific braking strategies, but instead account for a braking system in the worst possible state accepted by regulations.

The road borne disturbances, such as potholes, speed bumps, and road unevenness will generate forces with out-of-road plane motions. A sudden displacement of a leading vehicle due to a speed bump will create a stretching motion of the coupling of the following vehicle. Svensson et. al. (2016) claims that these road induced coupling forces dominate the forces in a clevis coupling. The claim is backed up with measurements from tests on test tracks and real traffic driving. It can be noted that these dynamic effects are local in the vehicle combination. They are not to any significant way dependent on the length of the vehicle or the total mass. However, it is unclear in which situation maximum forces will be generated, e.g., potholes versus unbalanced braking, such as in equation (1). Ultimately, the normative cases should be selected using a balance of frequency and risk and should be well-grounded in statistics and experience.

For low-speed maneuvers, such as parking or switchyard operations, articulation angles can be very high. These high articulation angles may even hit mechanical end stops, where the leading and trailing units meet outside the joint. The distance between the coupling force and the meeting point of the vehicles will act as a lever for forces causing an increase in the articulation angle. Forces generated here can be extreme. However, this situation may be regarded as misuse of the equipment and may not be relevant for the present investigation.

6. Conclusion

This report extends the ISO 18688:2013 standard (ISO 2013) requirements for coupling forces to two new vehicle combinations: Truck-B-double and B-triple. Due to the semi-empirical nature of the existing ISO standard, means to validate the new expressions had to be developed. Simulations were employed to compare the coupling forces and coupling requirements of combinations both covered and not covered by the standard.

The comparison between results from the simulated joint forces, the ISO requirements, and the new expressions, suggest that the latter are in line with the expectations and should not be considered controversial as a base for legislation for the new combinations.

The ISO standard and the equations proposed in this report are based on the take-off situation where the leading vehicle is generating a propelling force. As discussed earlier this may not be the worst-case scenario in terms of coupling force amplitudes. Based on a combination of simulations and measurements, a thorough investigation is recommended to establish worst-cases and a balance between the in-road plane and out of road plane forces at couplings.

The ISO standard is conservative in requirements, but not due to the nature of the considered scenarios. Conservativity is built into the expressions where an exaggerated force and other heuristic means are used to ensure generous safety margins, effectively detaching the expressions from the nature of force generation. A different approach should be taken, where the physical interpretation can be preserved in the derived expressions, and all assumptions are explicitly motivated. However, the expressions need to be simple enough to be implemented in legislation and not depend on parameters that are hard to obtain. Hence, the problem of model complexity needs to be studied in parallel with the investigation of worst-case normative load scenarios.

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