

EFFECT OF PLATOONING ON THE STRUCTURAL RELIABILITY OF BRIDGES



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Abstract

The structural safety of bridges and viaducts is determined by comparing the expected resistance of the structure with the effect of the load on this structure. The probability that the structure or parts of the structure will fail as a result of this load must be sufficiently small (order 10^{-4} during service life -). Considering the expected service life of approximately 80 years, expected changes of the load in the future, such as truck platooning, must also be taken into account in the design of new and the assessment of existing bridges and viaducts. In this respect the objective of the research at hand is to define likely scenarios of how platooning may develop in the future. In order to determine the dominating parameters that affect the development of platooning over time, an actor analysis has been performed. With respect to the response of the bridge, the following parameters play a dominant role: 1) Total weight of the platoons, 2) Number of vehicles in a platoon, 3) Distance between the trucks in the platoon and 4) 'Degree of matching'. The resulting scenarios are presented in this paper.

Keywords: truck platooning, structural safety, bridges and viaducts

1. Introduction

Truck platooning is seen as an interesting possibility for trucks to, in a safe way, drive closer behind each other and better using the existing road capacity. The trucks are not physically, but electronically coupled to each other within the platoon. The first truck determines the speed and route, while the other trucks follow without needing the aid of their driver.

Truck platooning is a development with potentially a large impact on the current mobility. The question “*What does truck platooning look like in 2033?*” cannot yet be answered with certainty. Nevertheless, we would like to know what the effects of truck platooning will be on for example the fuel consumption and traffic safety, but also on the structural safety of bridges and viaducts.

In this paper scenarios of the future development of truck platooning (hereafter: platooning) in time have been sketched, based on the research presented in [1]. The goal of these scenarios is to serve as a basis for the quantification of the effects of platooning on bridges and viaducts (hereafter: bridges). The scenarios are based on a set of parameters that are identified in this research. These parameters are relevant for the load effect on bridges and may change as a result of the introduction of platooning. Every parameter can take multiple values.

The presented scenarios on the developments of platooning are mainly based on existing knowledge and experience of experts on the subject. The scenarios are based on interviews with experts that are active in the field of platooning and their insights and expectations have been combined. This paper can be seen as a first step in getting an insight in the structural effects of platooning on bridges and as a basis for discussion about these effects.

1.1 Objectives

It is expected that platooning may influence the safety level of certain bridges, especially if platooning is adopted on a significant scale. The extent to which and how platooning will develop is unknown. The objective of this research is to define 3-5 likely scenarios of how platooning may develop in the future. Two moments in time have been chosen: three years and ten years after the introduction of platooning. According to the experts the rate of the developments is rather high which makes it difficult in looking further in the future than ten years.

1.2 Research Approach

The development of platooning is dependent of several parameters, such as technical requirements, adoption by the transportation companies and regulations. In this paper two tracks have been followed to identify the relevant parameters for the development of platooning in relation to the load on bridges: first, the parameters that have been identified in earlier research which possibly affect the structural safety [2]. Secondly, parameters that are influenced from mobilities point of view are identified, based on an actor analysis and interviews.

Each of these parameters can take one or more values. For example the distance between the trucks in a platoon may vary in time as a result of developments in the technology. Scenarios have been drawn based on the expected values of the different parameters. Together with experts the most likely scenarios for three and ten years after the introduction of platooning and a worst-case scenario have been chosen. We have assumed that platooning will be introduced in 2023 and in the short period until introduction (2018-2023) no new parameters influencing the development of platooning will occur.

In order to determine the effect of platooning on the structural safety of bridges, the most important parameters governing the behaviour of these structures are studied for different load conditions and types of structures. It appears that the effect differs for mechanisms related to low cycle fatigue and

the structural safety for quasi static load conditions for both concrete and steel bridges. Moreover, a substantial difference in bridge geometries may be expected, since for short span bridges and structural components (influence length less than 20 m) the effect of platooning is not noticed, at least as long as platooning does not lead to an increase of the total number of trucks, for example due to global shifts in the transport sector where the average weight and number of vehicles change.

On the other hand, for the load bearing structure of long span bridges (influence length up to 100 or even 200 m), it may be expected that both the load effect due to quasi static load conditions as well as due to fatigue load conditions will be unfavourable for the calculated design loads. For large spans, larger loads may be expected depending on the number of vehicles in the platoon. Moreover, the probability will increase that more heavy vehicles will be present together on a bridge.

The development of platooning is largely depending on the choices made by several actors such as the Ministry of transport, transport companies and the developers of platooning soft- and hardware. In order to determine the dominating parameters that affect the development of platooning over time, an actor analysis has been performed. The actor analysis includes an analysis of all the actors involved in platooning and their means, objectives and interests. The actor analysis has been complemented with interviews and resulted in parameters that are likely to change as a result of the introduction of platooning. The parameters resulting from the actor analysis have been compared to the parameters influencing the load on the bridge. The resulting parameters that are both likely to change and influence the loads have been used as part of the scenarios.

When it is assumed that the total distribution of the traffic does not change (for example due to shift in average weight or shifts between transport modalities), it is expected that the following parameters for the platoons play a dominant role in the structural behaviour of bridges

- Total weight of the platoons
- Number of vehicles in a platoon
- Distance between the trucks in the platoon
- Degree of matching

1.3 Scope

The research is limited to the platooning of trucks, other vehicles (e.g. cars) have not been considered. In selecting the parameters of influence for the loads on bridges, especially parameters that change due to the introduction of platooning as well as influence the load on bridges have been considered.

We have chosen to include the development of platooning over time in the scenarios. According to the consulted experts it makes hardly sense to make predictions for more than about ten years after the introduction of platooning, because of the rate of the developments. We assume that platooning will be introduced in 2023 and that three years after introduction (2026) is a reasonable first reference point. Directly after introduction the degree of adoption and matching¹ is highly uncertain. The expectation is that *“By 2023, it should be possible to drive across Europe on motorways with multi-brand platoons, without needing any specific exemptions for crossing national borders – a prerequisite for international transport”* [3]. The second reference point is ten years after the introduction of platooning, in 2033. We may reasonably expect that the most trucks could have the platooning technique onboard, since the average term of renewal lies at around seven years for trucks in The Netherlands.

¹ In section 2 the definitions of the degrees of adoption and matching are discussed.

1.4 Reading Guide

The next section (section 2) describes the parameters relevant for mobility and identified by means of actor analysis and interviews. The parameters relevant for the loads on bridges are used as a basis for the development of scenarios in section 3. Section 4 contains the conclusions and recommendations.

2. Identification of Parameters

We started the identification of parameters through two “tracks”: reasoned from the structural behaviour and reasoned from mobilities point of view. For the “*structural behaviour track*” we used the identification of parameters that are relevant for the load effect as described in [2]. This is elaborated in paragraph 2.2. For the “mobility-track” an actor analysis and interviews with experts on the subject have been done. The results have been presented in paragraph 2.3. First we start with the type of bridges and viaducts where platooning is relevant for in paragraph 2.1.

2.1 Influence Length of Bridges and Viaducts

In the research in [2] a distinction has been made into different types of structures and details. Except the material and the geometry, the influence length (L) of the structure part is one of the main parameters. In Eurocode EN 1991-2 [4] the following values for the influence lengths L are taken: $L=20$, $L=50$, $L=100$ and $L\geq 200$. Therefore, we define the following categories:

1. Short influence lengths. This concerns bridges with a short span where only one truck fits ($L\leq 20$ m) or (parts of) structures with an even smaller span such as crossbeams ($L=5$ to 10 m) or troughs ($L<1$ m).
2. Influence lengths where the effect of one or more trucks are noticeable. Typically bridges with an influence length of $L=20$ to 50 m.
3. Bridges with a medium influence length of $L=50$ to 100 m.
4. Large influence length ($L>100$ m, practically seen $L=100$ to 200 m).

For Which Type of Bridges is Platooning Relevant?

The maximum allowable length of a tractor trailer is 16.50 m in the Netherlands. For a truck trailer the maximum allowable length is 18.75 m. We assume both types of trucks participating in platoons. Although the weighted average is close to 17.00 m [5], conservatively 16.50 m has been used in this study, because this is considered more unbeneficial for the load effect.

For (parts of) bridges with an influence length $L<20$ m, platooning is considered not relevant, because the effect of the second and third vehicle may be neglected in the total load effect (only one truck fits the influence length). The larger the influence length, the larger the influence of multiple trucks. Therefore, the following categories for the influence length are considered:

1. 20 m – 50 m
2. 50 m – 100 m
3. 100 m – 200 m

On bridges of category 1 (influence length $20 - 50$ m) approximately 2.5 trucks from a platoon fit, based on a truck length of 16.50 m and a conservative spacing of 5 m. By means of the expected decreased spacing between the trucks, the mass on the bridge and therefore the load, increases. The same holds for bridges of category 2 (almost 5 trucks) and category 3 (approximately 9,5 trucks). Figure 1 shows the three categories.



Figure 1 – From top to bottom a category 1, 2 and 3 influence length with the maximum number of trucks (16.5 m) and spacing of 5 m. The picture of the truck does not (necessarily) represent the actual truck type.

2.2 Structural Behaviour Track

In [2] two forms of loads have been distinguished: static loads and fatigue. The size of the static load is mainly governed by loads with a large return period, the spacing between trucks and the overload. With respect to platooning it is therefore relevant how often a platoon passes a bridge, the spacing between trucks and/or between the axles of the trucks and whether and in what weight trucks are overloaded. For fatigue the number of passages of heavy vehicles with a frequent probability of occurrence are of main importance.

When we group the parameters identified in [2], like axle load, distance between axles and spacing between trucks, we can make the following overview:

1. Vehicle weight
 - Vehicle type, mass, length
 - Number of axles, axle load, axle spacing, axle drive
 - Overload
 - Better utilization of existing trucks resulting in on average higher loads
2. Weight per platoon
 - Spacing between trucks (intervehicle distance)
 - Number of trucks in platoon
 - Correlation between vehicle weights in a platoon
 - Way in which platoons are initiated (planned versus spontaneous)
 - Harmonica-effect for entering and exiting
3. Distribution of the load in longitudinal direction: number of platoons
 - Absolute growth of truck transport (by lower costs or modal shift)
 - Spacing between platoons
 - Part of platoons w.r.t. regular traffic
4. Distribution of the load in transverse direction
 - Hunting oscillation, the more or less lateral swaying deviation from the straight course, leading to a locally different distribution of the load
 - Overtaking of/by platoons (probability of two platoons driving next to each other)

With this grouping, all parameters relevant for the traffic load on the structure can be related in the next step to the development of platooning from a mobility perspective.

2.3 Mobility Track

From a mobility perspective the expected development of platooning in the future is relevant. An actor analysis has been used as a method to identify the parameters. In the actor analysis the most important actors that are relevant for platooning and their main means, interests and objectives have been identified. The analysis does not pretend to be complete and has been used as a basis for interviews and structuring the results. Based on the actor analysis and the interviews, the following parameters have been identified:

- Certain vehicle types, certain minimum/maximum mass, certain minimum/maximum length of the trucks
- Technical requirements on the axle load, axle distance, number of axles and axle drive
- Vehicle mass and spacing
- Spacing between platoons
- Number of trucks in a platoon
- Taking over of platoons
- Traffic jam
- Distribution of trucks over the road
- Heavy platoons
- Degree of adoption and of matching
- Degree of loading and overloading
- Modal split and modal shift
- Hunting oscillations
- Harmonica effect for entering and exiting

In the next paragraph this list of parameters has been used as a starting point to identify the parameters that are relevant for the structural reliability.

2.4 Summary and Conclusions

In this paragraph the parameters that are relevant for the scenario analysis and are identified in the previous paragraphs are summarized. We make a distinction between the relevant parameters which are considered in the scenario analysis and the so-called non-relevant parameters, which are the parameters which are not taken into account in the scenario analysis. Parameters are taken into account in the scenario analysis if we expect that they will lead to a change as a result of the introduction of platooning or if the change is relevant for the structural safety of bridges.

Relevant Parameters

The relevant parameters are as follows. For every parameter the values that we take into account is included:

5. Vehicle weight and distances
 - a. Parameter position and dynamic distance
 - b. First position and fixed distance
6. Number of trucks in a platoon
 - a. 2 trucks (2-platoon)
 - b. 3 trucks (3-platoon)
7. Degree of adoption and degree of matching
 - a. Probability of one or more platoons very small
 - b. Probability of one or more platoons is realistic
8. Hunting oscillations
 - a. More damage
 - b. Equal damage
 - c. Less damage

These are the relevant parameters within the boundary condition that only normal transport with a maximum weight of 50 tons and a maximum length of 18.75 meters is allowed to take part in platooning. The parameters can adopt multiple values dependent of the developments in the area of platooning. The relevant parameters are taken into account into the scenario analysis. Depending of the technical developments, the hunting oscillations can become a non-relevant parameter when these hunting oscillations remain unchanged with respect to the current situation.

Boundary conditions

In this paragraph the parameters are listed that have been identified and that are not relevant for the scenario analysis. These parameters are assumed to be constant and are therefore seen as boundary conditions. These are the following parameters:

1. Certain vehicle types, certain minimum/maximum length of the truck
2. Technical requirements to axle load, axle distance, number of axles and axle drive
3. Distance between platoons
4. Taking over of platoons
5. Traffic jam
6. Degree of loading and overloading
7. Modal split and modal shift
8. Harmonica effect
9. Distribution of trucks over the road
10. Heavy platoons

The non-relevant parameters are not included in the remainder of the research.

3. Scenarios

3.1 Parameters

From the previous section it appears that four parameters are of importance for the development of platooning in the relation to the loads on bridges. From every one of these four parameters their relationship to the scenarios is identified:

1. Vehicle weights and distances
For this parameter two values are chosen: a parameter position and a dynamic distance between the trucks or the first position and a fixed distance between the trucks. The vehicle weights and distances within a platoon is not an evident parameter. In case of the first position and a fixed distance, calculations can be made with the heaviest truck from a sample and a fixed distance of e.g. 6 or 10 meters. These distances are now often used if we look at the fuel benefits. For the parameter of a parameter position and a dynamic distance this is more difficult. For the order of the trucks the order of the sample can be taken, but for a parameter distance the question remains what distance to be used. At this moment insufficient information is available. Possibly a solution can be found in a variation of distances between 6 to 15 meters.
2. Number of trucks in a platoon
Directly after introduction of platooning we assume a platoon of two trucks and 10 years after introduction we assume a platoon of three trucks. For the loads on structures with a relative short influence length it does not matter whether it is a 2- or a 3-platoon. For structures with an influence length of a category 2 or 3 this is logically important.
3. Degree of adoption and matching
At the introduction of platooning we assume a low degree of matching leading to a very small probability that two or more platoons are on a bridge at the same time. Reasonably this situation does not have to be taken into account. Ten years after introduction the matching degree will be higher and then it is reasonable to assume that on a regular basis two or more platoons are on a bridge at the same time provided that the bridge is of sufficient length. In theory this can be two 2-platoons, two 3-platoons or a 2- and a 3-platoon at the same time. For the distance between the two platoons a conservative distance of 20 meters may be assumed.
4. Hunting oscillations
For the hunting oscillations it is unclear what the (im)possibilities are with respect to platooning. In principle there are three possibilities. One, there is hunting oscillation and damage is the same. Two, there is little or no hunting oscillation and the programming is in such a way that specific

details in the structure are taken into account which may result in less damage. And three, there is little or no hunting oscillation, but the programming cannot take into account specific details of the structure which can potentially lead to more damage for specific details. For the scenario analysis we assume all three possibilities may occur.

3.2 Scenarios

The parameters and the values of those parameters, can be described in the form of an event tree. Each of the branches of the event tree is a separate scenario. A scenario consists of different events, in this case the values that the parameters can take. Although in this research the probabilities of occurrence of the different events have not been identified, based on the interviews an estimation of the most likely scenarios for 2026 and 2033 has been made. Moreover, an estimation has been made of a worst-case scenario for the loads on the bridges. For each of the influence lengths an event tree is constructed. The event trees for bridges of category 2 and 3 are the same. For bridges of category 1 the event tree is different because no third truck fits within the influence length. Moreover the degree of matching that is relevant for the probability that multiple platoons influence the details of the structure is not relevant because of the limited influence length. The scenarios with three trucks and the values for the degree of matching are therefore not included in the event tree.

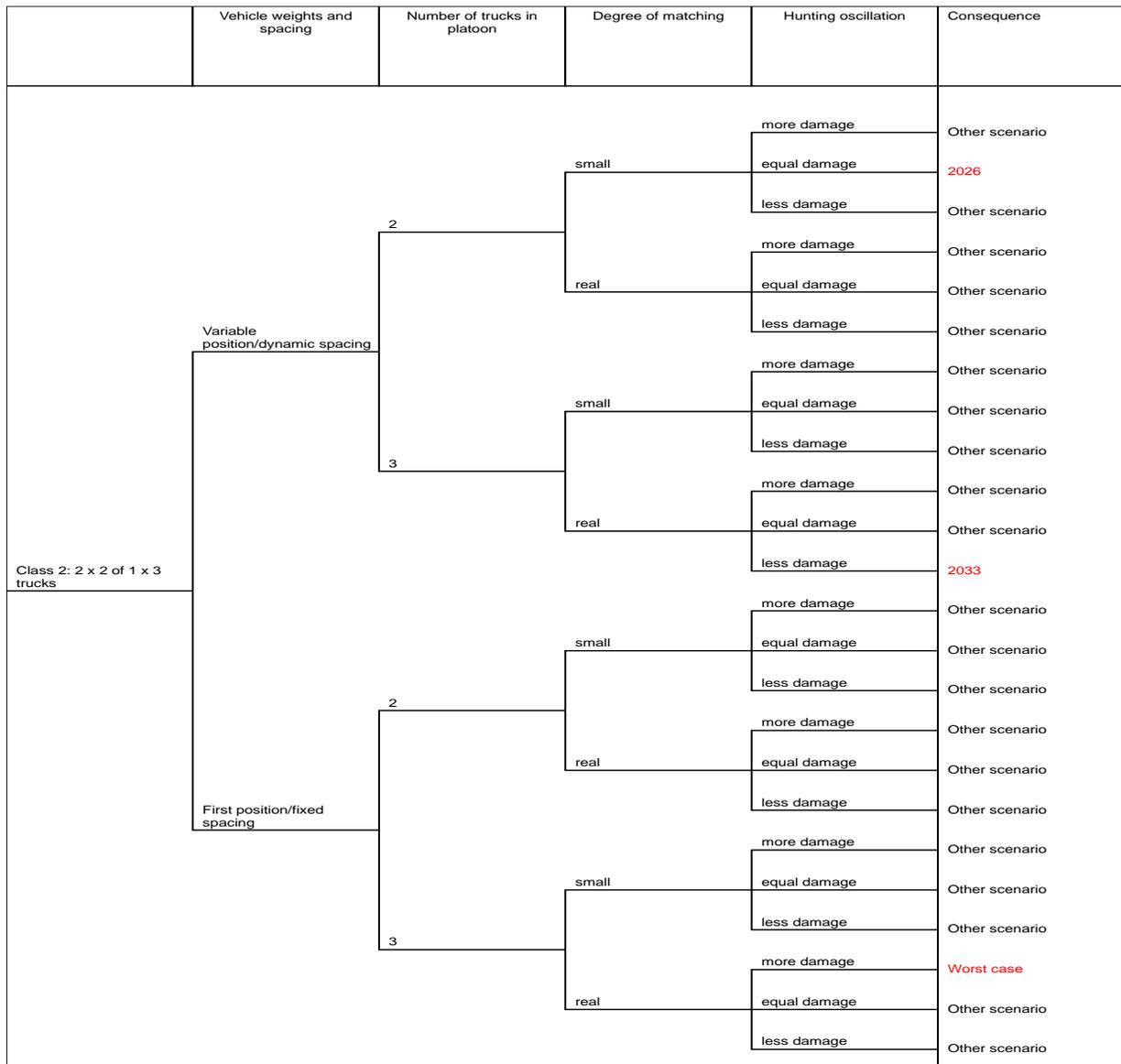


Figure 2: Event tree for an influence length L = 50-100 m and L = 100-200 m (category 2 and 3)

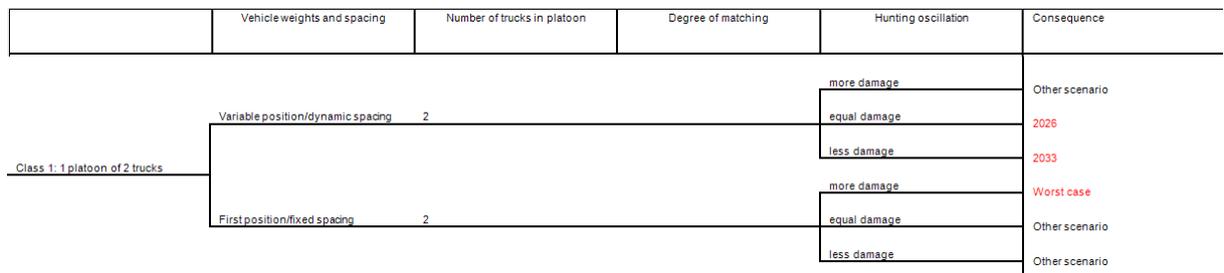


Figure 3: Event tree for an influence length L=20-50 m (category 1)

From Figure 2 and Figure 3 follows that the expectation is that in 2026 truck platooning takes place with two trucks per platoon driving based on parameter position and dynamic distance. There is a low

degree of matching resulting in low probability of multiple platoons on the influence length. The hunting oscillation has not changed and results therefore in a like damage with current situations.

From the figures also appears that the expectation is that in 2033 truck platooning takes place with three trucks per platoon that drive together based on parameter position and dynamic distance. The degree of matching has increased resulting in a higher probability of multiple platoons at the same time on a bridge. The platooning technique has been developed in such a way that the damage resulting from hunting oscillations is less than current situation. The platoons may be guided passed possible critical details of the bridge.

From the figures appears that it is the expectation that the worst-case scenario exists of platoons of three trucks that drive together based on first position and fixed distance. The degree of matching is higher resulting in a higher probability of multiple platoons at the same time on a bridge. The platooning technique is not capable of guiding trucks along critical details seems, likely resulting in more damage than in current situation.

3.3 Follow-up Study

For the further detailing of the scenarios it is important to know what follow-up analyses for which type of structures need to be performed. The most important load cases are static loads and fatigue loads. For static loads especially the extreme load during the life-time of the structure is important. This load has a small probability of occurrence. For fatigue loads the criterium is that the expected damage during the service life of the structure is not too large. The damage is mainly determined by a combination of the number of variations and the effect of the load on the structure based on the S-N curve of the material. When we refer to [7] we see that both the static as the fatigue loads are determined for three influence lengths, smaller than 2 meters, smaller than 20 meters and smaller than 200 meters. For each of these influence lengths the governing parameters for the failure mechanism of a certain structural part are given. Next, we go into detail for the relevant structures and analyses for this research.

Static and Fatigue Loads, Influence Length $L < 20$ m

The behaviour of structures and parts of structures with an influence length smaller than 20 meters are mainly governed by axle loads and tandem loads and in some situations even the wheel pressures. The scenarios that are developed for platooning do not foresee a change in these parameters except for the hunting oscillation. The hunting oscillation is expected on a short term to remain the same and for the longer term to become smaller. The current scenarios for platooning therefore seem to have no negative effects for the loads on these (parts of the) bridges.

Static Loads, Influence Length $L < 200$ m

The load on this influence length (mainly concerning the bearing structure) is governed by the weight of the vehicle and the probability of multiple heavy vehicles on the bridge. The parameter that is important is the spacing between the trucks of the platoon and the distance from the platoon to a single truck in front of or behind the platoon. The scenarios that are defined for platooning foresee an important change in this parameter, namely the distance between the trucks. Also the number of platoons is important. For an increasing number of platoons, the probability of having multiple platoons or platoons together with other heavy vehicles at the same time on the bridge is increasing as well.

Fatigue Loads, Influence Length $L < 200$ m

For this influence length (mainly concerning the bearing structure) for the failure mechanisms of steel bridges mainly the variations in vehicle weights is important, where especially heavy vehicles with a frequent probability of occurrence are important. The parameters that are of main importance are the spacing between the trucks and the number of platoons. The scenarios that are developed for

platooning foresee an important change in this parameter, namely the distance between the trucks in a platoon gets smaller. Furthermore, the number of vehicles are of importance. The scenarios however do not foresee changes in the number except the autonomous growth.

Conclusion

Platooning is only relevant for the static and fatigue loads for influence lengths between 20 and 200 meters where the spacing between the trucks and the number of trucks in a platoon are relevant. The frequency of a platoon on a bridge and thus the degree of matching is only relevant for the fatigue loads.

4. Conclusions and Recommendations

Following from the expected developments in truck platooning and the behaviour of bridges and viaducts to these developments, the most important parameters in truck platooning influencing the structural safety of these structures are identified for different load conditions and types of structures. Based on these parameters in truck platooning and their expected developments, detailed scenarios have been formulated for three and ten years after the introduction of platooning (2026 and 2033) for different influence lengths. Also, worst-case scenarios have been identified in current research.

4.1 Detailed Scenarios

For each of the influence lengths we detail the three scenarios for 2026, 2033 and worst case and visualize the platoons.

Influence Length $L = 20\text{-}50\text{ m}$, Scenario for 2026

In 2026 truck platooning takes place with two trucks per platoon on basis of parameter position and dynamic distance. The minimal distance between the trucks is 13 meters, except for heavy vehicles where the distance will be larger with a maximum of 27 meters for the heaviest trucks of 50 tons. Trucks that are not part of the platoon are assumed to have a distance of at least 20 meters. The length of the platoon is therefore at least 46 and maximum 60 meters. For the latter case the platoon does not fit exactly within the total influence length. Because of the short influence length only one platoon fits in the influence length, this is visualized in Figure 4. The hunting oscillation is expected to be unchanged and results therefore in alike damage with current situation.



Figure 4: 2-platoon on bridge category 1 ($L=20\text{-}50\text{ m}$, the truck represents all sorts of trucks including truck-trailers, the blue beam represents the bridge)

Influence Length $L = 20\text{-}50\text{ m}$, Scenario for 2033

In 2033 truck platooning takes place with three trucks in a platoon that drive together based on parameter position and dynamic distance. The minimal distance is reduced to almost 7 meters and for heavy trucks the distance is reduced to 13 meters. The 3-platoon therefore has a minimum length of 63.5 meters. This platoon does not fit within the influence length of 50 meters. Therefore, only two trucks fit on the influence length and the total weight is therefore unchanged. Compared to the scenario in 2026, only the distribution of the weight over the structure differs. Because of the short influence length, multiple platoons do not fit within the influence length and the platooning technique

is advanced in such a way that the damage due to hunting oscillations is less and the platoons can be guided along critical details. This means a positive effect for the fatigue load.

Influence Length $L = 20\text{-}50\text{ m}$, Worst-case Scenario

In the worst-case scenario trucks travel on a fixed distance with the heaviest truck in front. As mentioned before, some bridges, depending on the location, maybe loaded by platoons with relatively heavy trucks. For the calculation in the worst-case scenario a platoon with two trucks with each 50 tons could be considered. Because it is not unambiguously whether the shortest or the longest distance between the trucks is the worst case, in the calculations the distance between the trucks may be varied from 7 to 13 meters. For the hunting oscillations it is assumed that the damage will be larger as a result of no hunting oscillations, but the platooning technique is not capable to lead the platoon along the critical details.

Influence Length $L = 50\text{-}100\text{ m}$, Scenario for 2026

In 2026 truck platooning takes place with two trucks per platoon that travel together on the basis of parameter position and dynamic distance. The minimal distance between the trucks is 13 meters and for heavy trucks 27 meters is assumed. The distance between the platoon and other trucks is 20 meters. The length of the platoon is therefore minimum 46 meters and maximum 60 meters. Based on the influence length and the length of the platoon maximum three trucks can be placed on a category 2 bridge. This is visualized in Figure 5. Based on the influence length it is not possible to have multiple platoons on the bridge. The hunting oscillation is assumed to be unchanged and therefore results in alike damage with current situation.



Figure 5: 3-platoon

Influence Length $L = 50\text{-}100\text{ m}$, Scenario for 2033

In 2033 truck platooning takes with three trucks in a platoon that drive together based on parameter position and dynamic distance. The minimum distance is based on experience, reduced to almost 7 meters. For heavy trucks a distance of 13 meters is assumed. A 3-platoon has then minimum length of 63.5 meters and a maximum length of 75.5 meters. With these spacings maximum one 3-platoon and one single truck fit within the influence length. This is shown in Figure 6. The total weight is therefore possibly a little bit higher compared to the 2026 scenario. Because of the influence length no multiple platoons fit within the influence length. The platooning technique has developed in such a way that the damage as a result of hunting oscillations is less, because the platoons can be guided along critical details. This means a positive effect for the fatigue load of steel bridges.



Figure 6: 3-platoon and part of a single truck

Influence Length $L = 50\text{-}100\text{ m}$, Worst-case Scenario

In the worst-case scenario, the trucks drive in a 3-platoon on a fixed distance with the heaviest truck in front. As mentioned in the previous paragraphs some bridges, depending on their location, are loaded by platoons with relatively heavy trucks. For the calculation of the worst-case scenario a platoon with

three heavy trucks could be considered. Within the influence length another single truck can be taken into account. The worst-case with a distance between the trucks of 7 meters is therefore the weight of $4 \times 50 = 200$ tons. The damage due to hunting oscillation is assumed to be larger, because the platooning technique is not able to guide the platoon along the critical details. Therefore, the load on the critical details possibly will increase.

Influence Length $L = 100-200$ m, Scenario for 2026

In 2026 truck platooning takes place with two trucks per platoon driving together based on parameter and dynamic distance. The minimum spacing between the trucks is 13 meters and for the heaviest trucks 27 meters. The distance between the platoon and a single truck is at least 20 meters. The minimum length of a platoon is therefore 46 meters and the maximum length is 60 meters. A maximum of three 2-platoons fit on the influence length of a category 3 bridge. This is shown in Figure 7. The hunting oscillation is expected to be unchanged and therefore results in a similar damage as the current situation.



Figure 7: Three 2-platoons

Influence Length $L = 100-200$ m, Scenario for 2033

In 2033 truck platooning takes place with three trucks per platoon that drive together based on parameter position and dynamic distance. The minimum distance between the trucks has been reduced to almost 7 meters and for heavy trucks the distance is 13 meters. A 3-platoon has therefore a minimum length of 63.5 meters and a maximum length of 75.5 meters. With these spacings there fit two 3-platoons and one single truck on a bridge. This is visualized in Figure 8. The total weight is therefore higher than the scenario of 2026. The technique has advanced so much that damage as a result of hunting oscillations is less. The platoons can be guided alongside critical details which results in a positive effect on the fatigue load for steel bridges.



Figure 8: 3-platoons and one single truck

Influence Length $L = 100-200$ m, Worst-case Scenario

In the worst-case scenario the trucks drive in a 3-platoon based on a fixed distance with the heaviest truck in front. As mentioned before some bridges, dependent on the location, can be loaded by platoons with relatively heavy trucks. For the calculation of the worst-case scenario a platoon with three heavy loaded vehicles could be considered. With this influence length maximum 7 trucks fit on the bridge resulting in a weight of maximum $7 \times 50 = 350$ tons. The damage due to hunting oscillation is assumed to be larger because the platooning technique is not capable to guide the platoon along critical details.

4.2 Recommendations

In the next phase of this research analyses are foreseen to quantify the effect of platooning on the structural safety of bridges and viaducts, based on measured distributions of vehicles, the so-called WIM data. Based on the scenarios identified in the current research a number of variations is possible to take into account into the analysis. We recommend:

- Calculation of the current situation without platooning and comparing that with the scenarios as proposed in current research. Considering the use of the Dutch road network, it may also be

interesting for analysing and comparing the results of scenarios including 32 meters combinations, dual, long and heavy vehicles. These are trucks with a length of 32 meters and a weight of maximum 75 tons. Also, it would be interesting to calculate the long and heavy vehicles. These vehicles have a length of 25.5 meters and a maximum weight of 60 tons [7]. For studying the effect of the maximum allowable vehicle weight a scenario may be investigated for a maximum vehicle weight of 40 tons for platooning trucks (rather than 50 tons). Based on these alternatives and the calculations insight can be gained into the effect of the various variants.

- As the result of the introduction of platoons possibly more taking over will take place on the second lane, because the platoon is possibly just a little slower than a single truck. At this moment it is not clear if this is really the case. These possible extra take-over movements may result in an additional load on the second (fast) lane. It is recommended to take this phenomenon into account in the calculations of the effect on the structural safety.
- It is the expectation that the probability of multiple platoons at the same time on a long bridge is larger in the neighbourhood of locations where large number of trucks are loaded e.g. near harbours. The result is that the probability of multiple platoons on a bridge is locally increasing: 1) as a result of the location of the bridge in the road network and 2) as a result of the degree of adoption and the degree of matching of platooning in the time. Another distribution therefore results in the same effect as with a higher adoption and matching degree: larger probability of multiple platoons on a bridge. It is recommended to take this phenomenon into account in a follow-up study.
- Based on the situation above where a ship is loaded onto trucks, it is the expectation that on some bridges the probability that heavy platoons will occur, is higher than on bridges where random trucks meet each other on the fly. These platoons will result in more severe load effect for bridges than platoons that exist of random trucks, where it is likely that not all trucks have the maximum weight. Because it is the local probability of a heavy platoon, it is recommended to take effects related to the spatial variability of platoons into account.

5. Results

The result of the research is a number of scenarios for the short future (three years after introduction) and for ten years after introduction. Based on these scenarios probabilistic analyses with a Monte Carlo traffic load model can be performed, from which the load effect may be calculated. Based on a comparison of the load effect with a base scenario in which platooning is not considered, the effect of platooning on the structural safety of bridges and viaducts may be quantified.

The results presented at the conference will focus on the scenarios that will be relevant. The research in which the effect of platooning for the structural safety will be determined is expected in the future.

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