FALCON II. : INPUT FOR A EUROPEAN PBS DEFINITION: REVIEW OF VEHICLE LEGISLATIONS AND INFRASTRUCTURE DESIGN CRITERIA






Franziska Schmidt
PhD in Civil Engineering (2009) with habilitation (2017). Has been working for Ifsttar (former LCPC) since 2009, as a research engineer in bridge engineering, and recently in machine learning applied to monitoring data.

Sogol Kharrazi
PhD in Machine and Vehicle Design. Has been working as a researcher in vehicle technology at Swedish National Road and Transport Research Institute (VTI) since 2012. Also, an adjunct associate professor at Linköping University.

Sigurdur Erlingsson
Ph.D. in Civil Engineering (1993) and professor at VTI and UoI. Has been working with pavement design and performance development as well as impact of cold climate on pavement performance.

Carl Van Geem
Doctor in technical sciences (1996), Senior Researcher at the Belgian Road Research Centre, has been working on evaluation of the performance of existing roads and on pavement maintenance management since 2004.

Xavier Cocu
Agricultural Engineer; Specialization on rural engineering. Senior Researcher at BRRC since 2001, with expertise in various fields of road infrastructure safety and infrastructure safety management.

Bernard Jacob
Graduated from Ecole Poly-technique, has been working with SETRA, LCPC and Ifsttar in bridge engineering, heavy vehicle safety and regulation and WIM. Currently deputy scientific director with Ifsttar and president of ISWIM.

Abstract

In Europe, the regulation on weights and dimensions of trucks are complex: European rules are given by EC Directive 96/53/EC as modified by Directive (EU) 2015/719 [1]. These rules apply for international traffic, but countries can decide to add specific national rules. Moreover, these rules are often different from one country to another, due to policy choices and local history. More specifically, the impact of trucks on infrastructure has not always been the primary fact for defining these rules.

But in other countries or other research domains, performance based standards (PBS) are used to determine what is allowed, in terms of performance. For example, vehicles may be allowed in terms of their induced damage on bridges (Bridge Formula, see [2]) or dynamic behavior (PBS as in Australia for example). In another context, materials and structures are now often defined in calls for tender in terms of performance (durability, resistance for example).

In this context, the work package (WP) C (Fit for purpose road vehicles to influence modal choice) of CEDR project FALCON (Freight And Logistics in a multimodal CONtext) aims at developing Performance Based Standards [3]. For that, the first step is to create a state-of-the art of the European situation concerning vehicle policy and infrastructure. This paper summarizes this work: the first section gives insight on the European vehicle policy. The second section presents the infrastructure catalogue developed within the FALCON project. Finally, these infrastructure elements are characterized in terms of design criteria in Section 3.

Keywords: Performance Based Standard (PBS), Smart Infrastructure Access Policy (SIAP), vehicle policy, infrastructure design criteria.

1. Vehicle Policy

As part of the FALCON project, relevant European legislation for commercial heavy vehicles, and the corresponding regulations implemented in the countries involved in the FALCON project, namely Sweden, Norway, Netherlands, Germany, UK, France and Belgium were reviewed and compared. It should be noted that there are two types of European legislations: regulations and directives. Regulations have general application and are applicable in all member states, while directives set out general rules to be transferred into national law by each country as they deem appropriate.

Here a brief comparison of the length and weight limits in the studied European countries is presented, more information about the vehicle policy can be found in the deliverable 3.3 of the FALCON project. The length limit of motor vehicles in the EU is regulated in the R (EU) No 1230/2012 which is also applied in the studied countries [6]. However, in Norway it does not apply to timber transport, and in Sweden it is only applicable to modular vehicles. The length of vehicle combinations in Europe is regulated in the Directive 96/53/EC, with a limit of 16.5 m for articulated vehicles and 18.75 m for road trains. However, article 4 of the directive gives each member country the possibility to use longer vehicle combinations for national transport, if they are based on the modular system. A modular combination is a vehicle combination that consists of vehicle units defined in Annex I of the directive [7].

In Belgium, UK, France, Germany and The Netherlands, the European length limits apply. But Sweden has a length limit of 24m which is also the limit for timber transport in Norway, otherwise limits of 17.5 m and 19.5 are used for articulated vehicles and road trains respectively in Norway. European Modular System (EMS) combinations, which are 25.25 m combinations of EMS units are allowed in Sweden, Norway, Belgium, the Netherlands, and in 13 of the 16 provinces (Länder) in Germany.

The single axle load limits are very similar in the studied countries complying with the EU limits for international traffic stated in the Directive 96/53/EC: 11.5 t for driving axles and 10 t for other axles; however, France has a higher axle load limit of 13 t. The load limits for a bogie are also comparable and mostly complying with the Directive 96/53, but the reference axle distances for setting the bogie load limit are slightly different for some countries. For instance, in Norway 0.8 m and in France 0.9 m is used as the reference axle distance, below which the lowest load limit is applied, while in other countries 1 m is used which is the same as the EU regulations for international traffic. It is a similar case with triple axles loads, i.e. the load limits are comparable, but the reference axle distances are not uniform. Again, France allows higher load limits, e.g. up to 31.5 t on a tridem instead of 27 t, and Norway has the lowest load limit for an axle distance below 1 m.

The weight limit for a motor vehicle depends on its number of axles in all the considered countries and is quite similar to the European limits for the international traffic stated in the Dir 96/53/EC , the Netherlands is an exemption with higher limits. For regulation of the weight limits of trailers and semi-trailers, different approaches are used in each country. Commonly the weight limits are regulated based on features such as the axle distances, number of axles and the vehicle type. For instance, in Sweden the weight limit depends on the axle distance between the foremost and rearmost axles in the vehicle/vehicle combination, while in the Netherlands, the axle load limits and the total weight limit of the vehicle combination determine the weight limits on the constituent units, see Table 1.

Table 1. Vehicle weight limits (ton)

	EU International	Sweden	Norway	Netherlands	Germany	France	UK	Belgium Flanders & Wallonia
Motor vehicle	**18/25(26)[1]/32** 2/3/4+ axles	**18/25(26)[1]/31(32)[1]** 2/3/4+ axles	**19/26/26-32** 2/3/4+ axles	**21.5/28-31.5/34(37)[1]** 2/3/4+ axles	**18/25(26)[1]/32** 2/3/4+ axles	**19/26/32** 2/3/4+ axles	**18/25(26)[1]/30(32)[1]** 2/3/4 axles	**19/26/32** 2/3/4 axles
Trailer Semitrailer	**18/24** 2/3 axles	**GVW/GCW table** for axle distance	**10/18,20/24,27** 1/2/3 axles ST or CT **20/28/30** 1/2/3 axles FT or DY-ST	Depends on the axle distance and number of axles.	**18/24** 2/3 axles Trailer	**19/26** for 2/3 axles	**18/24** for 2/3 axles	**10/18/24** 1/2/3 axles Trailer **22-44** Semitrailer
Vehicle combination	**36/40** 4/5 axles Road train **36(38)[2]/40(44)[3]** 4/5 axles Articulated vehicle	**64** GVW/GCW table for axle distance	**50** GCW table for axle distance **60** EMS & timber	**50** **60** EMS	**28/36/40(44)[3]** 3/4/5 axles Road train **28/36(38)[2]/40(44)[3]** 3/4/5 axles Articulated vehicle	**38/40(44)[4]** 4/5 axles Road train **38/40(44)[4]** 4/5 axles Articulated vehicle	**26/36/40** 3/4/5 axles Road train **26/36(38) [2]/40(44)[3]** 3/4/5 axles Articulated vehicle	**29/35** TK2-CT1/2+ **36/42(44)[5]** TK3-CT1/2+ **39/44** 4/5 axles Other road trains **29/39/43(44)[5]** 3/4/5+ axles Articulated vehicle **60** EMS

[1] If driving axle is fitted with twin tyres and a) air suspension (or equivalent) or b) drive axle load does not exceed 9.5 t
[2] If the semitrailer axle distance is bigger than 1.8m and the driving axle is fitted with twin tyres and air suspension
[3] If carrying a 45-feet ISO container, 42t for if the motor vehicle has two axles and 44t for if the motor vehicle has three axles
[4] If the single axle load does not exit 12t [5] With air suspension CT=Centre Axle Trailer, FT=Full trailer, ST=Semitrailer, TK=Truck

It should also be noted that in the R (EU) No 1230/2012 and the Dir 96/53/EC, there are extra criteria that indirectly impose restrictions on the dimensions and load distribution of the vehicle to ensure maneuverability and traction (EC 2012). Examples of such criteria are the swept area in a roundabout, ratio of the load on steer or drive axles, and engine power based on the vehicle weight.

2. Infrastructure Catalogue

2.1 Pavements, pavement structures

The infrastructure catalogue developed within the FALCON project is the basis for the development of both the PBS and the SIAP (Smart Infrastructure Access Programme): indeed, on the one hand, the infrastructure catalogue distinguishes the various roads or road networks with various access policies; on the other, this catalogue shows the infrastructure elements for which the design criteria must be determined.
A series of assumptions have been made to establish this infrastructure catalogue: Only design values are considered regarding axel loads and tyre pressures, physical parameters such as layer thicknesses, material characteristics and ambient climate. Therefore, the considered infrastructure is supposed to be in a design (meaning nominal) state. Moreover, a second assumption assumes that only current design codes are considered.
This catalogue deals with three infrastructure types: pavements, bridges and tunnels. Geometrical and mechanical (load capacity) aspects are considered.

Pavements are multi-layer structures built on top of the subgrade soil. Their main structural function is to support the axle loads, and spread them downwards to the subgrade (natural ground) avoiding overstressing of all layers, that is reducing the induced stresses and strains to tolerable levels during all climatic conditions.
A typical pavement structure consists of:

- a surface course, which can be divided into a wearing course (or top layer), a binder course and a bound road base.
- Unbound base layers, usually divided in two layers: a base course and a subbase, both build of materials with good mechanical resistance.
- a pavement foundation: the subgrade (native soil), sometimes topped with a capping layer.

The main functions of the surface course is to provide good pavement surface characteristics (evenness, skid resistance), to ensure a good rolling quality and appropriate safety conditions for road users, and to protect the road base from the wear due to traffic loads, and from the penetration of water (impermeability). The main functions of the base layers are to withstand the loads induced by traffic (fatigue resistance), and to distribute the stresses on the pavement foundation. The capping layer protects the subgrade during the works phase, improves the homogeneity and bearing capacity of the natural subgrade, and protects it from frost actions.

European pavements can be categorized according to the materials used in the different layers, namely flexible pavements (with bituminous bound layers or asphalt concrete) or rigid pavements (with Portland cement concrete layers). Flexible pavement flex under traffic loading giving a localized deformation bowl under the load that is further distributed downwards over gradually increasing area that is proportional to the stiffness's of respectively layer. Rigid pavement structure's load transmission is different from flexible structures. It relies on the rigid slab action that spreads the loading over a large area. Further are pavement structures with both bituminous and concrete bound layers usually referred to as semi-rigid structures, see ***Figure 1***. The various layers may have different thicknesses depending on the country considered.

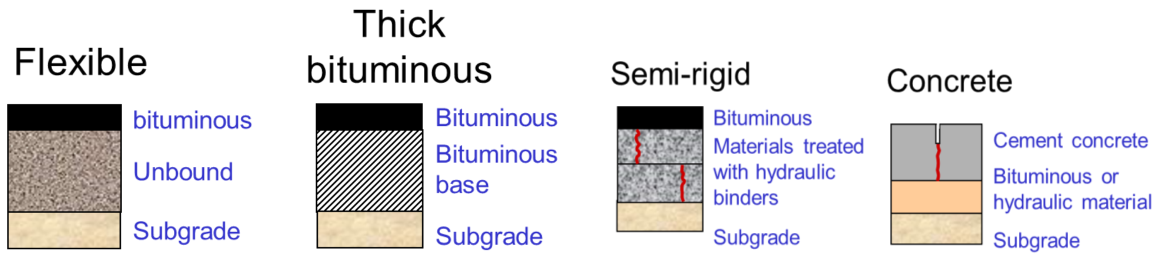

Figure 1: Typical pavement structures.

Thin flexible pavements (see figure 1a) consist of a relatively thin bituminous surface course (or asphalt concrete layer) resting on one or more layers of unbound granular materials. They are usually the most economical, but due to the low stiffness of the unbound granular base layers, they are only suitable for low to medium traffic levels. They are frequently designed to last for 20 years. The other types of pavements in Figure 1 are more suited for heavier traffic levels on main arterials roads and motorways. Concrete pavements are usually designed to last longer (30 to 40 years) than the tick-bituminous or semi-rigid pavements (20 to 30 years), they are usually more expensive to build but they need less maintenance.

Two damage phenomena are commonly studied in flexible pavement design: That is fatigue cracking (bottom-up cracking) starting at the bottom of the lowest bituminous bound layer and rutting that is accumulation of plastic deformation in the pavement structure. Fatigue is the phenomenon of damage induced by repeated applications of small traffic load actions. Fatigue laws express the relation between the number of applications of loads and tensile strain or stress leading to failure. Only bituminous pavements are subject to rutting. Rutting is the manifestation of accumulation of contribution of permanent deformation in the different layers of the pavement structure. Thus, all layer can contribute to the rutting development. Rutting design calculations are usually associated with the repeated induced vertical strain at the top of the subgrade material. From extensive rutting tests performed in different European countries with different tyres, tyre configurations, axle loads, inflation pressures, etc. (e;g. [8]) a tyre configuration factor (TCF) was defined. The TCF value relates the pavement wear of a given tyre to the pavement wear of a reference tyre. Within different axle categories (steered, driven or towed axle), there is a wide range of TCF values.
For rigid pavements the main steps in the structural thickness design are associated with calculations of critical stresses at three locations that are related to crack initiations due to traffic loading. These three locations are at the interior (center), the edge and corner of the proposed concrete slab. Usually the tensile stress at the top of the slab when loaded at the corner of the slab is the most critical one.

Road managers design pavement structures using a wide range of parameters such as the expected transport needs, the available materials, and climate conditions. Hence, the pavement structures vary from country to country and even along the road network managed by one road authority leading to a wide variety of pavement structures. For FALCON, the following main factors need to be considered in order to establish a representative “catalogue”, or a representative library of pavement structures:

- The type of pavement structure: thin flexible, thick bituminous, …, or concrete pavement,
- The level of traffic, expressed by the number of heavy vehicles (HV) per day and ESALs (Equivalent Single Axle Loads),
- The chosen level of service, which can be expressed by a factor of safety, or a risk of failure,
- The bearing capacity of the subgrade,
- The mechanical characteristics of the pavement materials.
- The ambient climate

Bridges can be described by influence lines, i.e. transfer functions from unit loads to the considered effects (mainly bending moments and shear forces at supports). Therefore, the main characteristics are the number of supports and the various span lengths.

2.2 Bridges

Bridges are classified using various criteria: depending of the type of structure (suspended, cable-stayed, …), of the materials (reinforced or prestressed concrete, steel, composite, …), of the number of spans (one, two, …), of the supports and the degrees of freedom (isostatic, hyperstatic), …

But when comparing the effect of one given type of vehicle on a bridge with the effect of another vehicle, it is sufficient to calculate the convolution of the characteristics of the vehicles (axle loads, distances between axles) with a structural information of the structure called “influence line”.

The influence line of a given effect (for example bending moment, shear stress, …) is a function which gives this effect when a unit force is applied to the structure.

Therefore, for the bridge catalogue of the FALCON a set of influence lines have been chosen, namely:

- One-span bridge, bending moment at midspan and shear at support, span lengths of 10~m, 20 m, 35 m, 50 m and 100 m,
- Two-span bridge, bending moment at midspan, at central support and shear on central support, both span lengths of 5 m, 10 m, 17.5 m, 25 m and 50 m (see Figure 2).

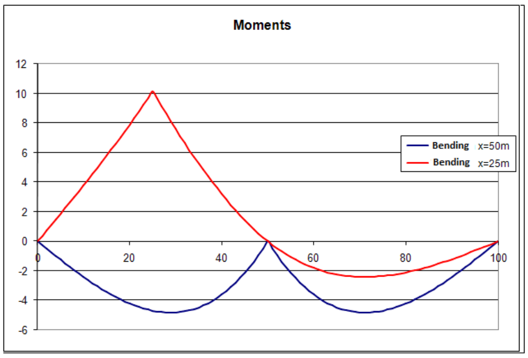

Figure 2: Bending moment at midspan ((red curve) and on support (blue curve), for two-span structure with both span lengths equal to 50 m.

2.3 Road geometry

The geometry of the road is an important point when talking about dimensions of trucks. Indeed, trucks have to be compliant, in a static and a dynamic way, with the existing infrastructure, meaning the roundabout, the right turn, left turn, the ramps, etc.
Road geometry is usually defined following several parameters:

- the horizontal alignment, consisting of straight sections connected by circular horizontal curves (themselves defined by their radius and length) and transition curve (horizontal curve with a varying radius to connect other elements);
- the longitudinal profile, characterised by grades (road slopes) connected by parabolic vertical curves (sags or crests) used to provide a gradual change from one road slope to another for a smooth vehicle navigation;
- the cross section, i.e. the number of lanes, their widths and cross slopes, as well as the presence or absence of various features like shoulders, curbs, sidewalks, drains and ditches
- other various elements like the clearance under bridges and in tunnels, etc.

Road geometry is strongly related to vehicle dynamics. The stability of vehicles depends on the observance of rules linking vehicle speed, radius of curves and cross slope. Road alignment also influences sight distance, which is an important factor for safety. While studies of contributing factors to road accidents show that human factors predominate, roadway factors are the second most common category of elements that influence the road safety performance.

For road design and depending on the road category (typically motorways, express roads, interurban arterials and ordinary roads), there are target or minimal acceptable values of geometrical parameters pertaining the curve radius, transition curve length, longitudinal profile, width of traffic lanes (the normal traffic lane width being 3,50 m) and shoulder, cross slope. Nominal values of some geometrical characteristics are provided in Table 2.

The geometrical characteristics of highway exit/access lanes, at-grade intersections and roundabout are also regulated to allow smooth left- or right-turn maneuvers, and crossing of roundabouts, see Figure 3.

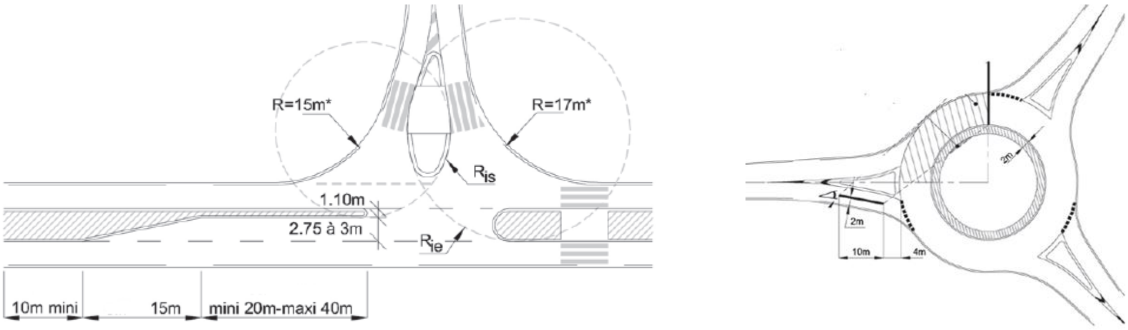

Figure 3: Example of the geometrical characteristics of an intersection (left) **and Nominal roundabout** (right; the radius of the outer ring should be between 15 and 25 m)**, from [4].**

Table 2. Nominal values of some geometrical characteristics in the studied European countries

Infrastructure feature	Nominal Values
Road Grade	**Sweden:** main roads: 6-8%, minor roads: 10% **Norway:** 6% **Netherlands:** motorways: 3-4%, main roads: 4-5%, minor roads: 6-7% **Germany:** motorways: 4-6%, country roads: 4.5% - 8% **France:** motorways: 5-6%, main roads: 7%, hilly main roads: 10/8% (with/out snow) **UK:** motorways: 3%, carriageways 4-6%, hilly carriageways: 8% **Belgium:** 4-8%
Lane width	**Sweden:** motorways: 3.5-3.75m, main roads: 3.0-3.75m, minor roads: 2.75-3.25m **Norway:** 3.25-3.5m depending on speed limit **Netherlands:** motorway: 3.5m, main roads: 3.0-3.25m, minor roads: 2.75-3.1m **Germany:** motorways: 3.25- 3.75m, country roads: 3.25-3.5m **France:** main roads: 3.0-3.5m (larger on bridges) **UK:** 3.35-3.65 m (depending on number of lanes) **Belgium:** motorways and main roads: 3.5-3.75m, whole range: 2.50-3.75m
Crossfall	**Sweden:** 2.5-5.5% **Norway:** min 2% **Netherlands:** 2.5-7% **Germany:** motorways: 2.5-6%, country roads: 2.5-7% **France:** straight lanes: 2.5%, curves: 2.5-7% (proportional to 1/R) **UK:** 2.5-5% (desirable, 7% = absolute maximum) **Belgium:** min 2.5%
Road curvature depends on speed limit	**Sweden:** min 100-1200m **Norway:** min 125-800m **Netherlands:** 160-1500m **Germany:** motorways: min 280-900m, country roads: min 200-900m **France:** min120-600m (higher if no crossfall) **UK:** min 180-1020m (for crossfall of 5%) **Belgium:** min 120-1600m
Roundabout dimensions	**Sweden:** reference outer & inner circles radius of 12.5m & 2m **Norway:** reference outer & inner circles radius of 12.5m & 2m **Netherlands:** outer radius of 10.5-16m (rural), 12.75-18m (urban) **Germany:** outer radius of 17.5-20m (7.5m lane), 20-25m (7m lane) **France:** no guidelines **UK:** no guidelines, junctions: min circular corner radius 6m (urban), 10m (rural) **Belgium:** no guidelines

3. Infrastructure Design Criteria

For the infrastructure elements included in the infrastructure catalogue, European design criteria have been compared. It has been observed that while the National design criteria are quite similar, differences exist.

2.4 Pavements, pavement structures

Most countries use mechanistic-empirical pavement design methods, which are similar in their principle. They are based on two main steps:

- A calculation of the stress-strain response of the pavement based on a reference load (generally defined as the "equivalent standard axle load", or ESAL), using a multi-layer linear elastic pavement model.
- The application of several pavement design criteria, which allow to calculate the number of standard axle loads (ESALS) which can be supported by the pavement before failure (also called the pavement life), in function of the maximum level of stress or strain calculated in each pavement layer.

In the design process the accumulated traffic loads during service life is converted into a number of Equivalent Standard Axle Loads (ESAL) that the pavement must support. The bearing capacity of the subgrade is expressed by its elastic modulus and the mechanical properties of the pavement materials comprise the elastic modulus, Poisson ratio and fatigue properties. The ambient climate, and in particular the temperature (single value, or several climatic periods) is considered for the bituminous materials, which exhibit temperature-dependent behaviour. Sometimes a factor of safety (or risk coefficient) is used to adjust the number of loads to failure. Based on the above-mentioned parameters the required layer thicknesses are calculated so the pavement can last for the required designed life.

Several of these design parameters are country-specific:

- The design lifetime of the structure is generally 20 years in Europe, but some countries may use up to 30 years (Belgium).
- The traffic volume and loads vary from one country to another, depending on the local economy and the geographical location. Moreover, the definition of ESAL (Equivalent Standard Axle Load) also slightly differs: generally, ESAL is given in equivalent 100 kN-axle loads (for a given configuration of tyres with given air pressure), but the French ESAL is expressed in equivalent 130 kN-axle loads.
- The fatigue and rutting criteria in the pavement structure are not expressed with the same formula and at the same location.
- Climatic parameters are also different from one country to another: obviously, the targeted temperature varies by countries, but also by region within a given country: e.g. in Sweden, this temperature is defined according to five climatic regions and six seasons per year. Frost-thaw can therefore be taken into account.
- Materials used in the pavement layers in different countries have different characteristics and thus the commonly used values for their elastic modulus and Poisson ratio as well as their fatigue properties are different.

Thus, there is no unique and standardized approach in Europe to design pavements. However, there is a general agreement about the main steps in the design framework that is the design approach and design criteria's. The design tool and the input parameters values for the mechanistic-empirical pavement design can differ for different regions or countries throughout Europe. However, this common ground in pavement design can be exploited in the development of a vehicle policy framework and a PBS

Bridge design is standardized by the Eurocodes. The Eurocode 1 specifies the actions on structures, such as wind loads, traffic loads [5], etc. These actions are described by load models, to be applied for the bridge (and other structures) design. Several traffic load models exist for calculation of extreme effects. Specific fatigue load models (five) are proposed for lifetime assessment, the simplest one being the most conservative and the most detailed being the less conservative. Some differences of the load model intensities are allowed by countries, by the application of α-factors.

2.5 Bridges

Bridge design is standardized in Europe through codes called Eurocodes: for example, Eurocode 2 is the code dedicated to the design of bridges and civil engineering structures in concrete (plain, reinforced, prestressed). Eurocode 3 is dedicated to steel construction. The traffic actions to take into account when designing bridges are given in Eurocode 1 [5]. More precisely load model 1 ("LM1") of Eurocode 1 defines the actions for extreme load calculations, whereas load model 3 ("LM3") are those for calculation of fatigue damage.
LM1 is composed of a uniformly distributed load, whose numerical values can be different between the traffic lane (slow or fast lane), and punctual vertical corresponding to axle loads. These values are nationally specific through the α-factors (see Figure 4 and

Table 3).

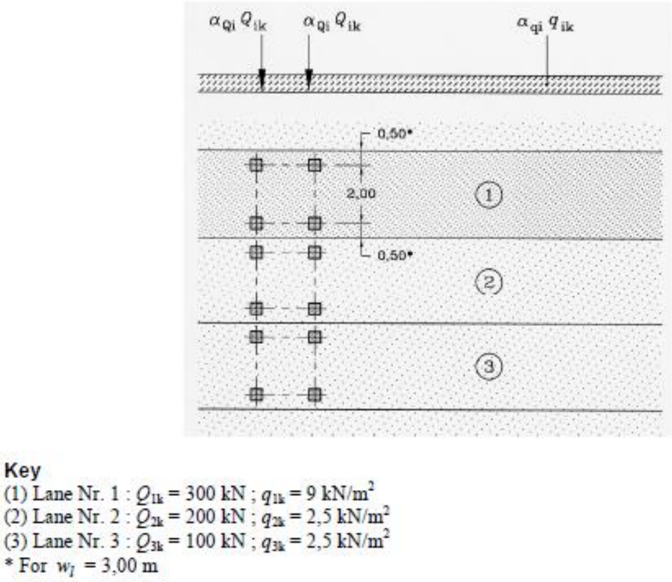

Figure 4: Load model 1 of Eurocode 1: on each lane (lanes 1, 2 and 3), an uniformly load and several punctual loads are applied. .

Table 3: Comparison of α-factors in several European countries (extracted from deliverable D3.4 of FALCON project).

Bridges	Norway	Netherlands	Germany	France	UK	Belgium
α-factor	Alpha-factors (LM1 of Eurocode 1): $\alpha_{Q1} = 0.6$ All the other alpha-factors= 1.0.	αq1 = 1,15 and for *i* >1 αq*i* = 1,40	$\alpha_{Q1} = 0.8$ $\alpha_{Q2} = 0.8$ The other alpha-factors α_{Qi} equal to 0. $\forall i, \alpha_{qi} = 1$	LM1: $\alpha_{Q1} = 1$ $\alpha_{Qi} = 1, \forall i \geq 2$ $\alpha_{q1} = 1$ $\alpha_{q1} = 1.2, \forall i \geq 2$ $\alpha_{qr} = 1.2$	LM1: $\forall i, \alpha_{Q1} = 1$ $\alpha_{q1} = 0.61$ $\alpha_{qi} = 2.2, \forall i \geq 2$	For new bridges: European class 1 (alpha-factors = 1) For existing bridges: Belgian class 2 (alpha-factors in general = 0,8).

So, while standardizing the design and the building of bridges in Europe, national coefficients make it possible to adapt the load models to national requirements.
It should be mentioned here that it is not possible to compare at a glance the various national load models (meaning that the effect on a given structure would depend on this infrastructure).

2.6 Road geometry

For road geometry, the design criteria are country-specific and the target values for the parameters (as explained in Section 2) are quite similar from one country to another. Therefore, in the FALCON project, only the cases of one main road and one secondary road are taken into account.

The design criteria can then be applied to vehicles included in the vehicle policy framework in order to determine the PBS.

4. Conclusions and Discussion

The work, presented here and in deliverables D3.2, D3.3 and D3.4 of the FALCON project, is the background for the development of Performance Based Standards, and then the development of SIAP. Indeed, the information on vehicle policy and different types of infrastructure allow determining which impact of vehicles on infrastructure is sustainable. This will give more flexibility for vehicle design and usability, and therefore for innovation in vehicle industry, without inducing increased damage on the existing road infrastructure, which is ageing and whose limited maintenance budget is decreasing.

References

[1] European Parliament and European Council, "Directive (EU) 2015/719," 2015, available online: http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32015L0719&from=EN.

[2] Maryam Moshiri, Jeanette Montufar, Bernard Jacob, Franziska Schmidt, Investigation on existing Bridge Formulae and background for the development of a European Bridge Formula, PIARC World Congress, Mexico City, 2011.

[3] B. Kraaijenhagen, T. Barth, K. Kural, J. Pauwelussen, I. Besselink, A. Prati, M. Meijs, H. Nijmeijer.: *Greening and Safety Assurance of Future Modular Road Vehicles, Book of requirements, Project EUREKA HTAS EMS*, 2014.

[4] Les échangeurs sur routes de type « Autoroute », SETRA, 2015.

[5] EN1991, Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges, 1991.

[6] European Commission, Commission Regulation (EU) No 1230/2012, implementing Regulation (EC) No 661/2009 of the European Parliament and of the Council with regard to type-approval requirements for masses and dimensions of motor vehicles and their trailers and amending Directive 2007/46/EC of the European Parliament and of the Council, 2012

[7] European Commission, Council Directive 96/53/EC, laying down for certain road vehicles circulating within the Community the maximum authorized dimensions in national and international traffic and the maximum authorized weights in international traffic, 1996

[8] “Effects of Wide Single Tyres and Dual Tyres”, COST 334 Report, 2001, available online www.rws.nl/rws/dww/home/cost334tyres