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Abbreviations

ABS	Anti-lock Braking System
AEBS	Advanced Emergency Braking Systems
CEDR	Conference of European Directors of Roads
EBS	Electronic Brake System
EMS	European Modular Systems
ESC	Electronic Stability Control
EU	European Union
FALCON	Freight and Logistics in a Multimodal Context
HCT	High Capacity Transport
ISO	International Organization for Standardization
LDWS	Lane Departure Warning Systems
MoU	Memorandum of Understanding
PBS	Performance Based Standards
SIAP	Smart Infrastructure Access Policy
SRT	steady-state rollover threshold
UNECE	United Nations Economic Commission for Europe
VDAM	Vehicle Dimensions and Mass
WHSC	World Harmonized Steady State Cycle
WHTC	World Harmonized Transient Cycle

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Management Summary

1. Introduction

The transport sector currently contributes to about a quarter of CO_2 emissions in the EU and is the only sector with an increasing trend (EEA 2016). One of the major drivers behind this trend is the growing demand for freight transport. Hence, the European Commission has set ambitious emission targets for the transport sector in its Transport White Paper (EC 2011a).

To align the EC goals and the means of National Road Authorities to cope with the growing freight transport demand, it is necessary to increase the efficiency of freight transport and logistics. Therefore, Conference of European Directors of Roads (CEDR) has financed the project Freight and Logistics in a Multimodal Context (FALCON) with the objective to acquire insight into:

- the possibilities for optimizing multi-modality and the impact that these might have on road infrastructure;
- assessment procedures and tools that enable NRAs to analyse policy measures that influence mode choice;
- the possibilities of Performance Based Standards for vehicles to increase the efficiency of freight transport and the impact this might have on road infrastructure and modal choice.

Review of the existing vehicle policy in Europe, as well as the international standards, is one of the first performed tasks within work package C of the FALCON Project. This is to enable development of a uniform performance based standards (PBS) scheme for Europe, or as referred in the FALCON project, a Smart Infrastructure Access Policy (SIAP).

This report provides a review of the international regulations for commercial vehicle combinations, including the PBS schemes in Australia, New Zealand and Canada, as well as the PBS investigations in South Africa and Sweden. Furthermore, the vehicle policies in the European countries involved in the FALCON project, or sponsoring it, are summarized and compared, and the similarities and differences are identified.

1.1. Regulatory Principles

There is a wide spectrum of regulatory principles which differ significantly in terms of how specific and well quantified they are, from “principle-based regulations” at one end to prescriptive regulations at the other. Principle-based regulations do not include quantified limits and are specified very broadly in terms of objectives (OECD 2005). For instance, a principle-based regulation for heavy vehicles can be that the vehicle operators need to minimize the risk of involvement of their vehicles in accidents, without specifying any policies for achieving the objective.

On the other hand, prescriptive regulations outline specifically how an objective should be achieved with explicitly defined and quantified mandates. Prescriptive regulations are currently the predominant regulatory principle used for regulation of heavy vehicles, worldwide. The common approach is setting limits on the vehicle weight and length to ensure safety and to protect infrastructure.

Performance based standards is a regulatory principle between the two abovementioned extreme approaches, which includes specific performance criteria/measures with quantified required level of performance. It is more precise than principle-based regulation, but provides more flexibility, which encourages innovative novel products, than prescriptive regulations.

2. PBS for Commercial Vehicle Combinations

PBS for regulation of heavy vehicles access to the road network has been implemented in Australia, Canada, and New Zealand. In South Africa and Sweden, implementation of a PBS scheme is under trial and investigation.

There are different approaches for implementing a PBS scheme in a regulatory framework. One approach is to use PBS as an underlying basis for developing prescriptive regulations like the Canadian example where “vehicle-envelopes”, defining the general vehicle layout, were developed using PBS. Another approach is used in Australia where PBS is used to determine access requirement for different parts of the road network and is complementary to the general prescriptive regulations. Considering the different implementation approaches, the degree of flexibility in a performance based regulation can vary considerably; greater flexibility might increase the risk of non-compliance if not complemented with a comprehensive enforcement strategy.

In the following sections, the PBS schemes in above-mentioned countries are briefly described.

2.1. Canada

In 1987, the result of the Vehicle Weights and Dimension Study, a major research study to identify HCT vehicles with minimal impact on infrastructure and satisfactory dynamic performance, was presented. The study was undertaken for the Road Transport Association of Canada, by University of Michigan Transportation Research Institute. It included regulatory principles for interprovincial heavy vehicle weights and dimensions in Canada, based on the seven performance based standards below (VWDS 1987):

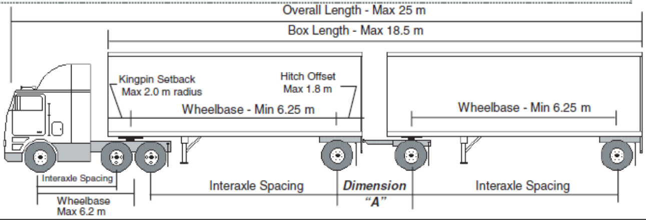
- Static rollover threshold
- Dynamic load transfer ratio
- Friction demand in a tight turn
- Braking efficiency
- Low-speed offtracking
- High-speed steady-state offtracking
- High-speed transient offtracking

A national implementation committee developed detailed specifications for the most common vehicles based on the regulatory principles. In this work, they used a prescriptive approach based on performance standards (VWDS 1987). These specifications were used to develop a national Memorandum of Understanding (MoU) on Vehicle Weights and Dimensions. All Canadian provinces implemented the MoU in 1989. The MoU was subsequently amended. The MoU defines eight vehicle categories based on the vehicle and axle configuration (NCHRP 2010).

Conclusively, PBS has been used in Canada as a basis for developing a prescriptive limits regulatory framework. Using the PBS and the results of a sensitivity analysis a set of size and weight limits, “vehicle envelopes”, defining the general vehicle layout were developed. This PBS/Prescriptive approach provides flexibility in design for various vehicle categories (Woodrooffe 2012). Examples of weight and length limits for one vehicle category are shown in Figure 1.

CATEGORY 2: A TRAIN DOUBLE

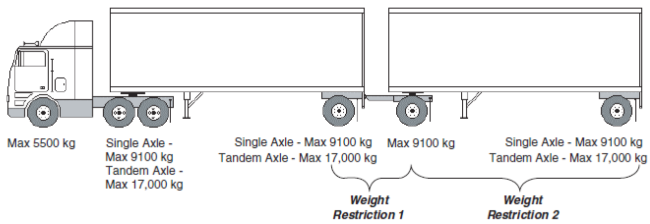
Part 1 - Dimension Limits



DIMENSION	LIMIT
Overall Length	Maximum 25 m
Overall Width	Maximum 2.6 m
Overall Height	Maximum 4.15 m
Box Length	Maximum 18.5 m
Tractor:	
Wheelbase	Maximum 6.2 m
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Lead Semitrailer	
Wheelbase	Minimum 6.25 m
Kingpin Setback	Maximum 2.0 m radius
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Hitch Offset	Maximum 1.8 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
Second Semitrailer or Full Trailer	
Wheelbase	Minimum 6.25 m
Tandem Axle Spread	Minimum 1.2 m/Maximum 1.85 m
Track Width	Minimum 2.5 m/Maximum 2.6 m
Interaxle Spacings	
Single Axle to Single or Tandem Axle	Minimum 3.0 m
Tandem Axle to Tandem Axle	Minimum 5.0 m
Dimension "A" (from the centre of last axle on the lead semitrailer to the centre of the first axle on the converter dolly or second trailer)	Not controlled

Category 2: A Train Double

Part 2 - Weight Limits



WEIGHT	LIMIT
Axle Weight Limits:	
Steering Axle	Maximum 5500 kg
Single Axle (dual tires)	Maximum 9100 kg
Tandem Axle:	
Axle Spread 1.2 m - 1.85 m	Maximum 17 000 kg
Weight Restriction 1: Sum of Axle Weights of Lead Semitrailer Plus Weight of Converter Dolly Axle	If Dimension "A" is less than 3 metres, the weight of the axle(s) on the lead semitrailer plus the weight of the converter dolly axle(s) is limited to a maximum of 17,000 kg for a two axle group or a maximum of 23,000 kg for a three axle group.
Weight Restriction 2: Sum of Axle Weights of Full Trailer or Second Semitrailer	The weight of the second trailer must not exceed the weight of the tractor drive axle(s) plus the weight of the axle(s) on the first semitrailer.
Gross Vehicle Weight Limits:	
Five Axles	Maximum 41 900 kg
Six Axles	Maximum 49 800 kg
Seven Axles	Maximum 53 500 kg
Eight Axles	Maximum 53 500 kg

Figure 1 – Length & Weight envelopes for a train double in Canada (NCHRP 2010)

2.2. New Zealand

New Zealand is one of the first countries to use performance based standards for regulating heavy vehicles. PBS has been used in New Zealand as a guide within a generally prescriptive regulatory framework since about 1989 (OECD 2005). In 2002 the size and weight regulations were moved into the Vehicle Dimensions and Mass (VDAM) Rule (De Pont et al. 2016). Again, PBS were used to develop some aspects of the regulation, including a new rule which required that all heavy vehicles shall have a minimum Steady-state Rollover Threshold (SRT) of 0.35g (LTSA 2002). The reason for this was that heavy vehicles were frequently involved in rollover accidents; there is research showing that low SRT correlates with high rates of rollover accident (Winkler et al. 2000, Muller et al. 1999).

In New Zealand, the maximum legal length for vehicle combinations is 20m and the maximum legal gross combination weight is 44t. In 2010 the VDAM Rule was amended to allow High Capacity Transport (HCT) vehicles to operate on routes that can accommodate them (LTSA 2010). The requirements for route-specific permitting of HCT vehicles are not formally specified in regulations; however, in practice the regulators have used performance based standards to determine whether the route can accommodate these vehicles. The New Zealand transport agency has a draft document on the policies for permitting vehicles that are over 23m but no more than 25m in length (NZTA 2013).

Although a formalised PBS system does not exist in New Zealand, PBS has been recognised as a useful tool to guide the regulators. Initially the performance measures used were based on those defined in the Vehicle Weights and Dimension Study undertaken for the Road Transport Association of Canada by University of Michigan Transportation Research Institute (VWDS 1987, De Pont et al. 2016). The Australian measures have been used, since its establishment in 2008. It has been complemented with some New Zealand specific performance measures, such as dynamic load transfer in a single lane change manoeuvre and high speed steady-state offtracking at a lateral acceleration of 0.2g.

According to de Pont et. al., the VDAM Rule was under review as of 2016, and as part of this review, a set of PBS applicable to New Zealand was being formalised. This process is considering which performance measures are most relevant to New Zealand and what are the appropriate pass/fail criteria (De Pont 2016).

2.3. Australia

Australia has the most comprehensive existing PBS approach to regulation of HCT vehicles, development of which took almost 10 years. The National Transport Commission in Australia initiated the process around 1999 and the scheme went into operation in October 2007. The PBS scheme in Australia is a voluntary process and operates as an alternative to the prescriptive regulations; it allows operators to use vehicles which do not conform to the prescriptive limits on mass and dimension, if their performance comply to a set of standards, covering safety, manoeuvrability and infrastructure. The Australian Design Rules including brakes, couplings, suspensions and tyres remain a requirement for all heavy vehicles (Arredondo 2012, ARTSA 2003).

One of the major phases of the PBS schemed development in Australia was identification of the essential performance measures, for which the following criteria were considered (NRTC 1999):

- Relevance to replacing and augmenting prescriptive limits
- Relevance to the entire vehicle, the load carried and the vehicle-road interaction
- Perceptions of importance to the identified outcomes in all zones of vehicle operation
- Inter-relationships between measures, a key measure being representative of similar measures
- Comprehension by all stakeholders
- Ability to be enforced with confidence.

During the process of establishing the performance standards, relevant information on heavy vehicle investigation where performance based approach has been used was gathered, including information on links between the crash rates of heavy vehicles and performance measures. Furthermore, the performance of the existing Australian fleet was assessed with respect to the candidate standards, using simulation and models of 139 representative heavy vehicles. The selected vehicles covered a diverse range of vehicle configurations, freight transport tasks and operating situations. As part of the existing fleet study, results from a number of field studies with various heavy vehicles in Australia were also reviewed (NRTC 1999, NRTC 2002). Additionally, workshops with interested parties and stakeholders were organized in all Australian states, where the candidate performance standards were discussed and adjusted accordingly. The intention was to evaluate the potential costs and benefits of the PBS scheme for all stakeholders and to enhance its credibility (NRTC 2001).

The Australian PBS scheme consists of sixteen safety standards and four infrastructure related standards. Thirteen of the sixteen safety standards are summarised in Table 1. with a description of each standard and a description of the associated test or manoeuvre. The three remaining standards – overtaking provision, ride quality and handling quality – are under review and are not likely to form part of the scheme in the short term. The four infrastructure standards are: pavement horizontal loading, pavement vertical loading, tyre contact pressure distribution and bridge loading. These standards are predominantly prescriptive due to the nature of the vehicle-infrastructure interaction. For each performance measure, four level of required performance are decided that correspond to different access to the road network. Level 1 represents unrestricted access to the Australian road network, with the most stringent performance criteria. Levels 2, 3 and 4 represent subsets of the road network, in increasing order of route restriction (NTC 2008).

Table 1 - Australian PBS scheme

Manoeuvre	**Safety Standard**	**Description**
Accelerate from rest on an incline	1. Startability	Self-explanatory
Maintain speed on an incline	2. Gradeability	Self-explanatory
Cover 100m from the rest	3. Acceleration Capability	Intersection/rail crossing clearance times
Low-speed 90 degree turn	4. Low-speed swept path	'Corner cutting' of vehicle combination
	5. Frontal Swing	Swing out of the vehicle's front corner
	6. Tail Swing	Swing-out of the vehicle's rear corner
	7. Steer-tyre friction demand	Maximal friction utilized by steer-tyres.
Straight road of specified roughness and cross-slope	8. Tracking ability of a straight path	Total road width utilized by a vehicle when responding to the road unevenness
Constant radius turn with increasing speed or tilt-table test	9. Static rollover threshold	The maximum lateral acceleration a vehicle can withstand before rolling over
Single lane-change	10. Rearward amplification	'Whipping' effect as lateral accelerations are amplified in trailing units.
	11. High-speed transient off tracking	Overshoot of the rearmost trailing unit
Pulse steer input	12. Yaw damping coefficient	The rate at which the yaw oscillations settle
Brake from 60 km/h to rest	13. Directional stability under braking	Directional stability and controllability of the vehicle under heavy braking

Another important aspect of a PBS scheme development is the assessment and implementation procedure. Figure 2**Error! Reference source not found.**, depicts the application and decision-making procedure for the Australian PBS scheme. The decision is made by the PBS review panel, based on the recommendation by the panel's Secretariat and assessment results. The PBS review panel is made up from a representative from each Australia state and territory, the commonwealth and an independent chairperson and deputy person, in total 11 people. The assessor is a person who has applied to carry out assessment of vehicles and has been authorized by the PBS review panel (Arredondo 2012). Compliance of a vehicle with these standards is assessed either via physical testing or numerical modelling. Numerical modelling has proved very effective, and is the most common form of assessment due to the cost and effort involved in testing a prototype vehicle.

The assigned permit by the PBS review panel might include some operating conditions relevant to the usage of the vehicle; examples of such operating conditions are: fitting an underrun protection device, displaying a long vehicle sign, road friendly suspension for the tandem axles, etc. In some circumstances, Australian road authorities may also require the vehicle to operate under the Intelligent Access Program (IAP) and/or to fit the vehicle with on board mass monitoring. The IAP is a national program for remote monitoring of the vehicles and is capable of monitoring vehicles' route, time and speed (Arredondo 2012).

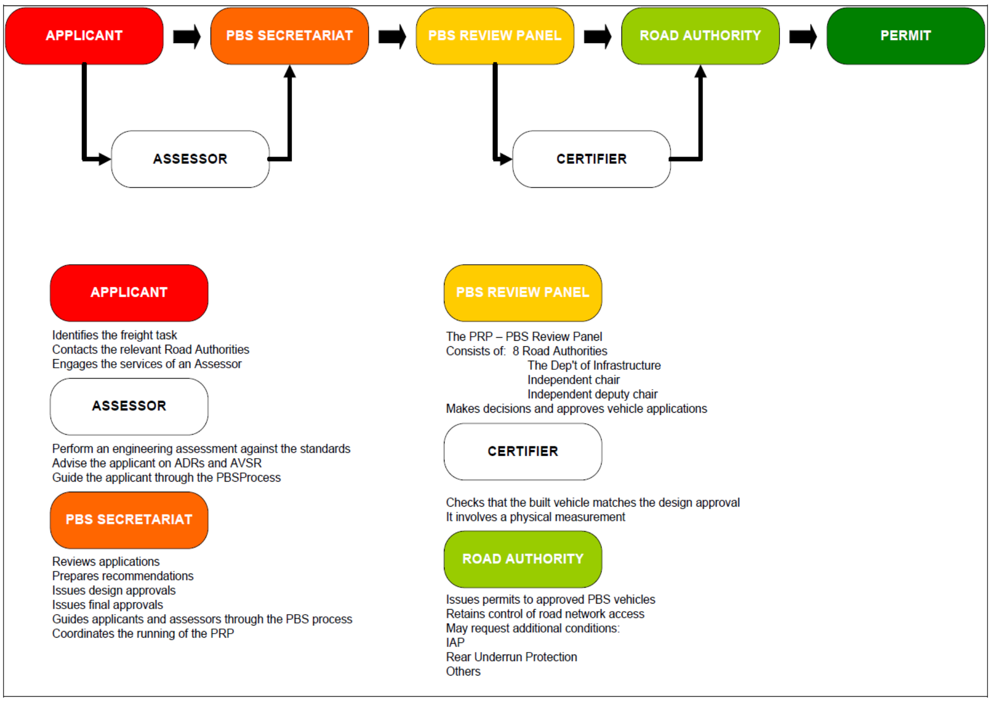


Figure 2 - Decision-making procedure of the Australian PBS scheme (Arredondo 2012)

2.4. South Africa

The existing legislation in South Africa, allows heavy vehicles with maximum overall length of 22m and maximum weight of 56t. However, in August 2004 a PBS committee was established to investigate the PBS approach and evaluate its potential in South Africa. Since 2008, demonstration projects of concept heavy vehicles are being carried out under the Road Transport Management System (RTMS) scheme. RTMS is an industry-led, voluntary self-regulation scheme, largely based on the Australian PBS scheme and suggested levels of performance. However, the infrastructure standards, such as the limits for axle loads and bridge formulas, are adapted to South African road traffic regulations and design codes of practice (Dessin et al. 2008, Nordengen 2012).

The first two PBS demonstration projects were implemented in forestry industry, more specifically within Sappi Forests Ltd and Mondi Business Paper. The vehicles were designed and manufactured to comply with the Level 2 safety standards of the Australian PBS system and went into operation in November and December 2007. Both Sappi and Mondi vehicles were a truck-dolly-semitrailer combination; the Sappi PBS vehicle was 27m long with total mass of 67.5t, while the Mondi PBS vehicle had an overall length of 24m and total mass of 64.1t, see Figure 3. The following extra safety features were incorporated in the design of one or both of the Sappi and Mondi vehicles:

- ABS and EBS
- Air suspension
- Pneumatic straps (self-tightening) for load securement
- Lift axles
- Underslung drawbar
- On-board load cells for payload control
- Central tyre inflation
- Vehicle tracking system
- Anti-rollover devices
- Special driver training

As of February 2017, the trial includes 215 participating vehicles, transporting commodities such as mining ore, timber, fuel, coal and sugar, with vehicles ranging in length from 22 to 40m, and in mass from 56 to 148t. To date, performance data for 92.4 million truck kilometres have been accumulated, together with data from conventional vehicles performing the same freight task on identical routes (the `baseline' vehicles). The data show that the demonstration vehicle fleet has yielded significant savings in terms of truck trips, fuel consumption, and emissions versus baseline vehicles. Furthermore, the demonstration vehicles yielded between a third and a half of the crash rate of the baseline vehicles, and have significantly fewer incidents of overloading, poor maintenance and other incidents (CSIR2017).

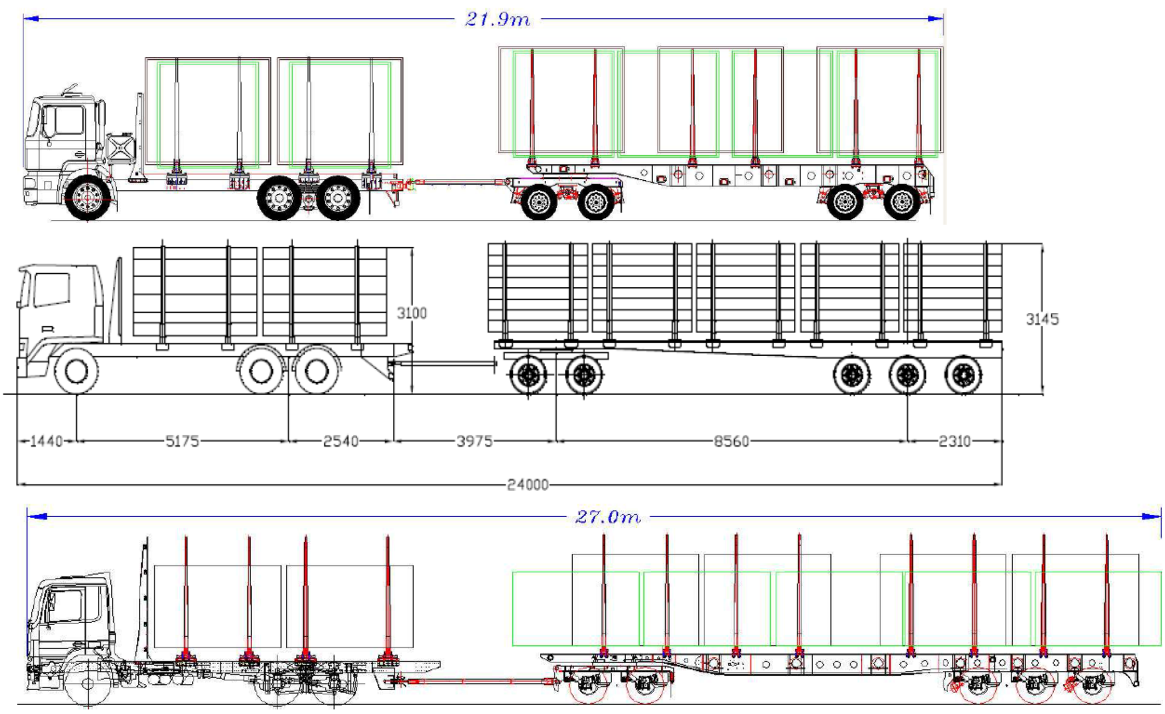


Figure 3 - The baseline vehicle and Mondi and Sappi demonstration vehicles (Nordengen 2010).

2.5. Sweden

The existing legislation in Sweden allows heavy vehicle combinations with maximum length of 25.25m and maximum weight of 64t on the road network. The government is considering opening part of the road network for 74t vehicles. Accordingly, the Swedish government is undertaking a large research program to investigate the use of HCT vehicles in Sweden, part of which is the project "PBS for HCT in Sweden". The project objective is to investigate the applicability of PBS in Sweden and to propose a regulatory framework based on PBS by identifying a set of performance based standards suitable for Sweden, with attention to winter road conditions (Kharrazi et al. 2014). The project started at the end of 2013 with reviewing the existing regulations, PBS approaches in other countries and other relevant literature. All the three domains of safety, infrastructure and environment were considered in this review. The gathered information is available as a public report (Kharrazi et al. 2015).

During the project, a candidate set of performance measures was identified and examined. One of the investigated issues in the project is the required level of modelling details for assessing different performance measures. For instance, the carried investigation for the traction related performance measures showed that the model complexity could potentially be kept relatively low, without a significant loss in accuracy. However, for winter/low friction conditions a higher level of complexity might be required (Bruzelius et al. 2016). A primary outcome of the project is the results of a study on the correlation between heavy vehicles performance in summer and winter conditions, which can be used for assigning required performance levels that also ensure safety in winter conditions, sample results can be found in (Kharrazi 2016). The development of an open PBS tool has also started during the project, results of which are published in a public report (Jacobson et al. 2017).

There have been several trials with HCVs, as part of the HCV program in Sweden. Since 2009, 50 vehicles have been operating in the program, saving about 10 million litres of diesel and 25000 tons of CO_2 (Skogforsk 2017).

3. European Legislations

In this section relevant European legislations for commercial heavy vehicles, and the corresponding regulations implemented in the European countries involved in the FALCON project are reviewed and compared. The references for regulation in FALCON countries can be found in (ARP 1994, Belgium 2017, CROW 2013a, ICTAAL 2015, Norway 2013, RDW 2012, UK2017a, UK2017b, Sweden 1998, Sweden 2016). This review is an extension to the pre-study conducted for CEDR on PBS for vehicle combinations with weight and/or dimensions exceeding the specified limits in the Directive 96/53/EC (Kharrazi and Karlsson 2015). The Directive 96/53/EC has been amended twice, in Directive 2002/7/EC and Directive (EU) 2015/719 (EC 2002, EC 2015).

It should be noted that two types of European legislations are cited in this report: regulations and directives. The difference is that a regulation has general application and is applicable in all member states, while directives set out general rules to be transferred into national law by each country as they deem appropriate. The following definitions, as defined in Dir 96/53/EC, are used in this report:

- **Motor vehicle:** any power-driven vehicle which travels on the road by its own means.
- **Semitrailer:** any vehicle intended to be coupled to a motor vehicle in such a way that part of it rests on the motor vehicle with a substantial part of its weight and of the weight of its load being borne by the motor vehicle, and constructed and equipped for the carriage of goods.
- **Trailer:** any vehicle intended to be coupled to a motor vehicle excluding semi-trailers, and constructed and equipped for the carriage of goods.

- **Articulated vehicle:** a vehicle combination consisting of a motor vehicle coupled to a semitrailer.
- **Road train:** a vehicle combination consisting of a motor vehicle coupled to a trailer.

3.1. Length Limits

The Length of motor vehicles in the EU is regulated in the R (EU) No 1230/2012 which is also applied in the studied countries (EC 2012). However, in Norway it is not applied to timber transport, and in Sweden it is only applicable for modular vehicles, see Table 3. Length of vehicle combinations in Europe are regulated in the Dir 96/53/EC, which is 16.5m for articulated vehicles and 18.75m for road trains. However, article 4 of the directive gives each member country the possibility to use longer vehicle combinations in its territory, 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 (EC 1996).

In Belgium, UK, France, Germany and the Netherlands, the European length limits are applied, but for EMS vehicles in the Netherlands, Germany and Belgium, which are allowed on parts of the road network, a maximum length of 25.25m is applied. It should be noted that in Belgium, the regions have independent regulations and EMS vehicles are allowed in Flanders and Wallonia regions, but not in Brussels; Brussels region has mainly urban roads. In Germany the EMS vehicles are allowed in 13 of 16 provinces (länder). In Sweden the overall length limit is 25.25m for a modular vehicle combination and 24m for other combinations. The length limit of a vehicle combination in Norway depends on the road category; the largest value is 19.5m with exception of 24m for timber transport and 25.25m for modular vehicles which are allowed on parts of the road network. The vehicle length limits in the studied countries are summarized in Table 3. Additional constraints on the loading length and axle distance are listed in Table 4.

3.2. Axle Load Limits

The single axle load limits are very similar in the studied countries and comparable with the EU limits for international traffic stated in the Dir 96/53/EC; however, France has marginally higher single axle load limit. For a bogie, the load limits are still comparable, but the reference axle distances for setting the bogie load limit are slightly different for some countries. For instance, in Norway 0.8m and in France 0.9m are used as the axle distance, below which the lowest load limit is applied, while in other countries 1m 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. France has higher triple axles load limits in comparison with other countries, and Norway has the lowest load limit for an axle distance below 1 m, see Table 5. It should also be noted that in Sweden and Norway the axle load limits depend on the road bearing capacity. Sweden has three categories of bearing capacity and Norway has four. The provided values in Table 5 are for the roads with the highest bearing capacity, BK1 for Sweden and BK10 for Norway.

3.3. Weight Limits

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 semitrailers 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, i.e. trailers and semitrailers.

The total weight limits for a vehicle combination in Germany and UK are same as the international traffic in the EU, which is 40t, or 44t in case of carrying a 40ft ISO container. In Belgium (Flanders and Wallonia) and France, the total weight depends on the axle configuration of the vehicle combination, but it is also limited to maximum of 44t. However, in Norway and the Netherlands, the total weight limit is 50t, and it is 64t in Sweden. Furthermore, in Norway and Netherlands, as well as Flanders and Wallonia regions in Belgium, EMS vehicles up to 60t are allowed. For more information, see Table 6.

3.4. Manoeuvrability and Traction

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 manoeuvrability 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. These regulations and their counterparts in the studied countries are listed in Table 7.

3.5. Brakes

Braking performance of heavy vehicles is another relevant issue that is extensively addressed in the existing regulations in Europe, and is also implemented in all the studied countries. In the R (EC) No 661/2009, which addresses the type approval of vehicles and their components, the UNECE regulation no 13 is listed as the regulation which should be followed for the brakes (EC 2009a). The ECE R13 includes criteria on deceleration, braking efficiency, parking ability on a grade and braking stability on a straight path and on a split friction surface, summarized in Table 2 (UNECE 2008).

Furthermore, in the R (EC) No. 661/2009, the mandatory fitment of a few active safety systems, including electronic stability control systems (ESC), advanced emergency braking systems (AEBS) and lane departure warning systems (LDWS) for heavy vehicles are included. In addition to the motor vehicles, the ESC system should also be fitted to trailers and semitrailers with air suspension and with less than four axles (EC 2009a). The detailed technical requirements for AEBS and LDWS are stated in R (EU) No. 347/2012 and R (EU) No. 351/2012, respectively.

Table 2 - Heavy vehicles brake regulation in Europe

Criteria	Required level of performance
Braking deceleration	**5 m/s2** from 6 km/h with engaged engine **4 m/s2** from 90 (80) km/h* with disengaged engine **4 m/s2** from 60km/h, after 20 repeated braking from 60 to 30km/h **3.3 m/s2** from 60km/h, after 6 km continuous braking
Braking efficiency Ratio of achievable deceleration to the ideally supported deceleration by the tyre/pavement friction	**>=75%** on roads with friction coefficient of 0.8 & 0.3 with an initial speed of 50km/h
Braking stability on a straight path	**Judged Subjectively** in a 4 m/s2 deceleration from 90 (80) km/h[1]
Braking stability on a split friction surface, measured by required steering correction	**< 240° (120°)**[2] from 50 km/h on a surface with kH>0.5, kH/kL>2
Parking ability on a grade	**>=18 %** single vehicle loaded up to GVW **>=12 %** vehicle combination loaded up to GCW, unbraked trailer

[1] Value in parenthesis is for tractors [2] Value in parenthesis is for the first 2 seconds

Table 3 - Vehicle dimension limits (m)

	EU International	Sweden	Norway	Netherlands	Germany	France	UK	Belgium Flanders & Wallonia
Motor vehicle	**12**	**12** (EMS)	**12**	**12**	**12**	**12**	**12**	**12**
Semitrailer	**12** kingpin to rear **2.04** kingpin-front corner	**12** kingpin to rear **2.04** kingpin-front corner (EMS)	**12** kingpin to rear **2.04** kingpin-front corner	**12** kingpin to rear **2.04** kingpin-front corner	**12** kingpin to rear **2.04** kingpin-front corner	**12** kingpin to rear **2.04** kingpin-front corner	**12** kingpin to rear **2.04** kingpin-front corner **15.65** Total length, long semitrailer trial	**12** kingpin to rear **2.04** kingpin-front corner
Trailer	**12**	**12** (EMS)	**12** (not timber)	**12**	**12**	**12**	**12** (not drawbar)	**12**
Vehicle combination	**16.5** Articulated vehicle **18.75** Road train	**24** **25.25** EMS	**17.5** Articulated vehicle **19.5** Road train **24** Timber **25.25** EMS	**16.5** Articulated vehicle **18.75** Road train **25.25** EMS	**16.5** Articulated vehicle **18.75** Road train **20.75** Car transporter **25.25** [2] EMS	**16.5** Articulated vehicle **18.75** Road train	**16.5** Articulated vehicle **18.75** Road train	**16.5** Articulated vehicle **18.75** Road train **18** road trains that do not fulfil Table 4 **25.25** EMS
Width	**2.55 (2.6)**[1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]	**2.55 (2.6)** [1]
Height	**4**	**Not regulated**	**Not regulated**	**4**	**4**	**4**	**Not regulated**	**4**

[1] For conditioned vehicles (vehicles fitted with a bodywork with insulated walls of at least 45 mm thick)

[2] Applied in 13 of the 16 provinces (Länder)

Table 4 - Additional constraints on the loading length and axle distance of road trains

	EU International	Sweden	Norway	Netherlands	Germany	France	UK	Belgium
Loading length behind the cabin	**15.65**	**21.86** (EMS)	**15.65**	**15.65** **21.82** (EMS)	**15.65**	**15.65**	**15.65**	**15.65**
From foremost point of the loading area to the rear end of the vehicle	**16.4**	**22.9** (EMS)	**17.15**	**16.4** (not EMS)	**16.4**	**16.4**	**16.4**	**16.4**
From rear axle of the motor vehicle to the front axle of the trailer	**>= 3**	**>= 3, 4, 5** [1]	**>= 3**	**>= 3**	**>=3**	**>=3**	**>=3**	**>=3**

[1] depends on axle configuration

Table 5 - Axle load limits (ton)

	EU International	Sweden (BK1)	Norway (BK10)	Netherlands	Germany	France	UK	Belgium
Single Axle Load								
Not a driving axle	10	10	10	10	10	13 (12)[3]	10	10
Driving axle	11.5	11.5	11.5	11.5	11.5	13 (12)[3]	11.5	12
Bogie Load								
d < 1 (0.8/0.9) [1] m	11 (11.5) [4]	11.5	10	11(11.5) [4]	11 (11.5) [4]	13.15	11 (11.5) [4]	11
1 (0.8/0.9) [1] <= d < 1.2 m	16	16	15	16	16	13.15+13(d-0.9)	16	16 (17) [5]
1.2 <= d < 1.3 m	16	16	16	16	16	13.15+13(d-0.9)	16	17 (18) [5]
1.3 <= d < 1.8 m	18 (19) [6]	18 (19) [6]	18 (19) [6]	18 (19) [6]	18 (19) [6]	19	18 (19) [6]	18 (20) [5]
d >= 1.8 m	20	20	20	as single axle	20	19	20	20
Triple Axle Load								
d < 1 (0.9/1.14) [2] m	21	21	16	21	21	22.05	21	21(22) [5]
1 (0.9/1.14) [2] <= d <1.3 m	21	21	22	21	21	22.05+13(d-0.9)	21	21(24) [5]
1.3 <= d <1.8 m	24	24	24	24(27) [6]	24	31.5	24	24(27) [5]
d >= 1.8 m	24	24	24	as single axle	24	31.5	24	as single axle

[1] 0.9 m for France, 0.8 m for Norway [2] 0.9 m for France, 1.14 for Belgium [3] For a 5-axled vehicle combination with 40<GVW<=44t [4] For driving axle
[5] Air suspension [6] For motor vehicle, if driving axle is fitted with twin tyres and a) air suspension (or equivalent) or b) drive axle load does not exceed 9.5 ton

Table 6 - 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, see Table 5	**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

Table 7 - Restrictions imposed by manoeuvrability and traction criteria

	EU International	Sweden	Norway	Netherlands	Germany	France	UK	Belgium
Outer & inner circle radius of the swept area (a 360° turn, if not stated otherwise)	**12.5 & 5.3**[1]	**12.5 & 5.3** Motor vehicle **12.5 & 2** (EMS) [2]	**12.5 & 5.3** **12.5 & 2** (timber) **13 & 2, 180°** EMS	**12.5 & 5.3, 270°** total length<=20 **14.5 & 6.5, 120°** 20< length<=23 **16.5 & 7.5, 120°** 23< length<=27	**12.5 & 5.3**	**12.5 & 5.3**	**12.5 & 5.3**	**12.5 & 5.3**
Rear swing out in a turn defined in the first row	**<= 0.8 (1.0)** [3] **m** Motor vehicle **<= 1.2 m** Articulated vehicle	**Not regulated**	**<= 0.8 (1.0)** [3] **m** Motor vehicle **Not regulated** Articulated vehicle	**<= 0.8 m** total length<=17 **<= 0.1.2 m** 17< length<=20 **<= 1.4 m** 20< length<=23 **<= 1.7 m** 23< length<=27	**<= 0.8 (1.0)** [3] **m** Motor vehicle **<= 1.2 m** Articulated vehicle	**<= 0.8 (1.0)** [3] **m** Motor vehicle **<= 1.2 m** Articulated vehicle	**<= 0.8 (1.0)** [3] **m** Motor vehicle **Not regulated** Articulated vehicle	**<= 0.8 (1.0)** [3] **m** Motor vehicle **Not regulated** Articulated vehicle
Steering axle load	**>= 20% of GVW**	**>= 20% of GVW**	**>= 20% of GVW**	**>= 20% of GVW**	**>= 20% of GVW**	**>= 20% of GVW**	**Not regulated**	**>= 20% of GVW**
Driving axles load	**>= 25% of GCW**	**Not regulated**	**Not regulated**	**>= 20% of GVW**	**>= 25% of GCW**	**>= 25% of GCW**	**>= 25% of GCW**	**>= 25% of GCW**
Engine power	**>= 5 kW/t**	**>= 5kW/t** (GCW <= 44 t) **>=220+2(GCW-44) kW** (GCW > 44 t)	**>= 5.15 kW/t** (GCW <= 40 t) **>= 206 kW** (GCW > 40 t)	**>= 3.68 kW/t**	**>= 5 kW/t**	**>= 5 kW/t**	**Not regulated**	**>= 5 kW/t**
Gradeability	**>= 12 %**[4]	**>= 12%**[4]	**>= 12 %**[4]	**>= 12 %**[4]	**>= 12 %**[4]	**>= 12 %**[4]	**Not regulated**	**>= 12 %**[4]

[1] Deemed to comply if $wb <= [(12.5-2.04)^2-(5.3+L/2)^2]^{0.5}$ where wb and L are wheelbase and width of the semitrailer

[2] Deemed to comply if axle distance <= 22.5m & wheelbase <= 8.15m

[3] For vehicles with retractable axles in the lifted position, or loadable axles in the unladen condition

[4] Starting five times within 5min at a grade with maximum load, for Sweden it is maximum load up to 44t.

3.6. Exhaust Emission

The exhaust emission regulation for heavy vehicles in Europe is stated in the R (EC) No 595/2009, commonly called Euro VI. The main regulation is complemented with the commission regulations R (EU) No 582/2011 and R (EU) No 133/2014, which stipulate all technical details regarding test procedures, measurement instruments and administrative procedures. Euro VI is applied in all the studied countries. The emission limits in Euro VI, listed in Table 8, has been in effect since 31 Dec 2013 for all new engines. The exhaust emissions are measured with respect to two driving cycles: World Harmonized Steady State Cycle and World Harmonized Transient Cycle, which have been created to cover typical driving conditions in Europe, USA, Japan and Australia (EC 2009b, EC 2011b, EC 2014a).

Table 8 - Euro VI emission limits

	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH4 (mg/kWh)	NOX (mg/kWh)	NH3 (ppm)	PM mass (mg/kWh)	PM number (#/kWh)
Compression Ignition (WHSC)	1500	130			400	10	10	8.0×10^{11}
Compression Ignition (WHTC)	4000	160			460	10	10	6.0×10^{11}
Positive Ignition (WHTC)	4000		160	500	460	10	10	6.0×10^{11}

CO: carbon monoxide, THC: total hydrocarbon, NMHC: non-methane hydrocarbons, CH_4: methane, NO_X: nitrogen oxides, NH_3: ammonia, PM: particulate matter, ppm: parts per million

3.7. Vehicle and Tyre Noise

The vehicle noise regulation in Europe are stated in the R (EU) No 540/2014, which replaced the directive 70/157/EEC in April 2014 and is similar to the UNECE regulation no 51, rev 3. The procedure for measuring the vehicle noise is based on the ISO 362:2007 pass-by-noise standard, where the noise of heavy vehicles is measured with the vehicles accelerating with wide open throttle on various gear settings past two microphones (one on either side), with an approach speed of 50 km/h, or 3/4 of the rated engine speed, whichever is the lower. The new regulation for vehicle noise adopts the ISO 362:2007 as the testing procedure and proposes new noise limits to be implemented in 3 phases. The new limits for heavy vehicles with engine power more than 250 kW are 82, 81, and 79 dB for the three phases, in effect in year 2016, 2020(2022) and 2024(2026), respectively. There are two different dates because new vehicle types and first registration are not treated equally (EC 2014b).

The tyre noise level limits are laid down in the European regulation R (EC) No 661/2009, which has been in effect since November 2012 for the so-called replacement tyres (tyres sold as replacement to the original-equipment tyres on new vehicles). The implementation time for original-equipment tyres is 2016 (EC 2009a). The tyre noise emissions should be measured in a coast-by-noise test, where the vehicle is travelling at high speed on a specified road surface, ISO 10844; when reaching the recording section, the vehicle should be in neutral gear with the engine switched off. The vehicle and tyre noise limits in the studied countries are same as the ones in the European regulations, see Table 9.

Table 9 - Heavy vehicle and Tyre noise limits in Europe

	Heavy Vehicle	Normal Tyre	Traction Tyre
Noise limit [db]	82, 81, 79[1]	73[2]	75[2]

[1] Limits for the three phases [2] Plus 1db for winter tyres

4. Relevant infrastructure features for a PBS scheme

In the previous section the existing regulations on heavy vehicles in FALCON countries were reviewed. These regulations address the EMS or conventional heavy vehicles with a limited length and weight. Thus, to ensure safety and manoeuvrability of HCT vehicles, if allowed on the road, extra requirements are needed. One possible approach is to use PBS as in Australia, Canada, and New Zealand.

Table 10 - Nominal value of the relevant infrastructure features for a PBS scheme

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%
Friction (winter maintenance)	**Sweden:** main roads: 0.35, minor roads: 0.25 **Norway:** main roads: 0.25, minor roads: 0.2 **Netherlands:** not regulated specifically for winter **Germany:** motorways and country roads: 0.32 **France:** not regulated **UK:** not regulated **Belgium:** not regulated
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, for Junctions: min circular corner radius 6m (urban), 10m (rural) **Belgium:** no guidelines

When investigating the performance of heavy vehicles with respect to safety and manoeuvrability measures, both vehicle design and infrastructure design should be considered; since they are highly related. If a heavy vehicle is to be permitted on a certain road network, features of the roads play a key role on the required level of performance from the vehicle. Likewise, when building a new road, the characteristics of the heavy vehicles to be driven on it, put demands on how it should be designed. In Table 10 the influential infrastructure features, relevant for a PBS scheme are listed with their nominal values in the studied countries (ARP 1994, AWV 1985, CROW 2013b, CROW 2013c, DMRB 2017, ICTAAL 2015, RAA 2008, RAL 2012, ROA 2014, SPW 1998, Statens vegvesen 2013, Trafikverket 2012a, Trafikverket 2012b, ZTV-ZEB-StB 2006). The main infrastructure design features which should be considered with respect to HCT vehicles are: friction, grade, lane width, curvature, roundabout dimensions and crossfall. Other important infrastructure aspects are availability of parking and rest areas, tunnel safety, safety barriers, turn lane length, distance between a railroad crossing and intersection, sight distance at an intersection and regulation of traffic signals.

5. Conclusions

In this report, the existing legislations which impose limitation on weight and dimensions of heavy vehicles are reviewed and compared within the European countries in the FALCON project. There are some differences in the applied length and weight limits in the studied countries, but there are also similarities which can be used to increase the cross-border fright transport efficiency. For instance, most of the studied countries, except from France and UK, allow the 25.25m EMS vehicles on part/all of their road network. However, the weight limit of EMS vehicles in Germany is kept as the EU limit of 40/44t, while the rest allow 60t EMS vehicles. The axle load limits are quite similar, the lowest limits can be used as a base to ensure applicability in all countries. Based on the gathered information for the studied countries, the lowest dimension limits which ensure applicability in all of them are listed in Table 12 and Table 13. Additional restrictions should be conformed to ensure applicability in all the studied European countries, see Table 11.

Introducing a uniform PBS scheme for allowing HCT vehicles in Europe will advance the efficient freight transport. In a PBS scheme, as shown in the reviewed schemes in other regions, the performance of heavy vehicles with respect to safety, manoeuvrability and effects on the infrastructure will be assessed. To do so both vehicle design and infrastructure design should be considered, since they are highly related. If a heavy vehicle is to be permitted on a certain road network, features of the roads play a key role on the required level of performance from the vehicle. A list of relevant infrastructure features, along with their nominal values in the studied countries, are provided in this report.

Table 11. Traction and manoeuvrability criteria which should be conformed to ensure applicability in all the studied European countries

Outer & inner circle radius of the swept area (360° turn, if not stated otherwise)	**12.5 & 5.3 m** **12.5 & 2 m** EMS
Rear swing out in a turn defined in the first row	**<= 0.8 (1.0) [1] m** Motor vehicle **<= 1.2 m** Articulated vehicle
Steering axle load	**>= 20% of GVW**
Driving axles load	**>= 25% of GCW**
Engine power	**>= 5 kW/t**
Gradeability	**>= 12 %[2]**

[1] For vehicles with retractable axles in the lifted position, or loadable axles in the unladen condition
[2] Starting five times within 5min at a grade with maximum load, for Sweden it is maximum load up to 44t.

Table 12. Length limits which ensure applicability in all the studied European countries

Motor vehicle	**12**
Semitrailer	**12** Kingpin to rear **2.04** Kingpin-front corner
Trailer	**12**
Vehicle combination	**16.5** Articulated vehicle **18.75** Road train
Width	**2.55 (2.6)**[1]
Height	**4**
Loading length behind the cabin	**15.65**
From foremost point of the loading area to the rear end of the vehicle	**16.4**
From rear axle of the motor vehicle to the front axle of the trailer	**>= 3**

[1] For conditioned vehicles (vehicles fitted with a bodywork with insulated walls of at least 45 mm thick)

Table 13. Weight limits which ensure applicability in all the studied European countries

Single axle load		
Not a driving axle	**10**	
Driving axle	**11.5**	
Bogie load		
d < 0.8 m	**10**	
0.8 <= d < 1	**11 (11.5)** [1]	
1 <= d < 1.04 m	**13.15+13(d-0.9)**	
1.04 <= d < 1.2 m	**15**	
1.2 <= d < 1.3 m	**16**	
1.3 <= d < 1.8 m	**18 (19)** [2]	
d >= 1.8 m	**19**	
Triple axle load		
d < 1 m	**16**	
1 <= d <1.3 m	**21**	
1.3 <= d <1.8 m	**24**	
d >= 1.8 m	**24**	
Motor vehicle	**18/25(26)[3]/32**	2/3/4+ axles
Trailer/Semitrailer	**10/18/24**	1/2/3 axles
Vehicle combination	**26/36(35)/40**	3/4/5 axles road train (TK2-CT2)
	26/36(38) [3]**/40(42,44)**[4]	3/4/5 axles articulated vehicle
	60	EMS

[1] For driving axle

[2] For motor vehicle, if driving axle is fitted with twin tyres and a) air suspension (or equivalent) or b) drive axle load does not exceed 9.5 ton

[3] If the semitrailer axle distance is bigger than 1.8m and the driving axle is fitted with twin tyres and air suspension

[4] 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

The existing European environmental regulations, also in effect in the studied countries, are already performance based. Thus, many of these regulations can be applied to HCT vehicles as well. In some cases, some adaptations might be required; for instance, in the case of the prospective European regulation on fuel consumption, HCT vehicles should be considered when determining the typical mission profiles and the fuel consumption limits.

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