TOWARDS PERFORMANCE BASED STANDARDS IN SWEDEN

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Abstract

The large increase in the goods transport demands, the growing congestion problem and the environmental concerns over transportation emissions and fuel consumption, make High Capacity Transport (HCT) vehicles an attractive alternative to the conventional heavy vehicle combinations on the roads in Sweden; an alternative which would also result in significant economic benefits. In order to introduce HCT vehicles in Sweden, the existing regulations should be modified and a proper way of regulating HCT vehicles and their access to the road network should be developed to ensure that a certified HCT vehicle would not have negative effects on traffic safety, infrastructure and environment. One possible solution is application of performance based standards (PBS); this paper presents a project called "Performance Based Standards for High Capacity Transports in Sweden" which investigates applicability of PBS to Swedish conditions. The project started in November 2013 and is planned to be completed by the end of 2016.

1. Introduction

The transport sector is facing a major challenge to reduce energy consumption and limit environmental impact; therefore, there is a great interest in increasing the efficiency of the transport system, particularly in scarcely populated countries with large raw material and transport demands, like Sweden. This makes the High Capacity Transports (HCT), i.e. longer and/or heavier vehicle combinations, an attractive solution. With HCT vehicles, the existing capacity of the road infrastructure can be utilized efficiently without requiring too high investments, and goods can be transported with fewer vehicles. This will consequently result in a reduction in the transport cost, fuel consumption, emissions and the traffic congestion.

The existing legislation in Sweden, allows heavy vehicle combinations, based on the European modular system, with maximum length of 25.25 m and maximum weight of 60 ton on the road network. However, dispensations of longer and heavier HCT vehicles for trial periods have been granted, such as the ETT-vehicle which was 30 m long with a maximum weight of 90 tons. The ETT-vehicle was tested within timber haulage industry and showed encouraging results; costs and emissions were reduced by 20 percent compared to a conventional Swedish 60 tons truck used in forestry. No negative impact on road safety was observed and road wear was not increased as the weight was distributed over more axles (Löfroth et al, 2012). Another example is the DUO2 project, with the double-trailer combination, which transports general cargo between two major cities Gothenburg and Malmö. The vehicle combination is 32 m long with a maximum weight of 80 tons (Cider & Ranäng, 2013).

The great interest in HCT has led to development of a roadmap for realization of HCT on Swedish road network by CLOSER, the Swedish arena for transport efficiency. The assumed target for the roadmap is that by the year 2030, 5% of all domestic transport on the road is operated by HCT vehicles. To achieve the HCT target by 2030, several actions and measures are proposed in the roadmap within the areas of infrastructure adaptation, information system, HCT logistics, HCT vehicle combinations and legislations. One of the key issues discussed in the roadmap is Performance Based Standards (PBS), which is a way of regulating HCT vehicles and their access to the road network. Under a performance based approach to regulation, standards would specify the performance required from vehicle operations rather than mandating how this level of performance should be achieved.

With the PBS approach, development of cost effective and eco-friendly HCT vehicles without negative effects on traffic safety, accessibility and infrastructure will be possible. PBS has been implemented in Australia, Canada, and New Zealand (OECD 2005). Lately, also South Africa has looked into the possibility of introducing PBS (Sharma and Kienhöfer, 2012), and there is an ongoing study on assessment of Dutch HCT vehicles with a PBS approach and its applicability to Europe (Kural et al, 2012). The country which has made the most progress in PBS is Australia; the Australian PBS scheme is divided in two parts: 4 infrastructure standards and 16 safety standards. For each standard, four performance levels are defined that correspond to different access levels to the road network (NTC 2008).

2. PBS Consortium in Sweden

In order to investigate applicability of PBS in Sweden, a consortium of research institutes, universities, transport authorities and truck and trailer manufacturers has been established. The consortium has been granted funding to initiate a project called “Performance Based Standards for High Capacity Transports in Sweden”. The project objective is to propose a performance based regulation of HCT vehicles and their access to the road network to support the development and implementation of efficient HCT vehicles without negative effects on safety, infrastructure and environment. The core of the proposed regulatory framework will be a set of performance based standards. The project goals are:

1. Identification of a set of performance based standards, suitable for Sweden with attention to snowy and icy road conditions. The purpose of the standards is to ensure that a certified HCT vehicle does not have negative effects on traffic safety, infrastructure and environment. Each performance based standard consists of three parts: a performance measure, a test procedure during which the performance of the vehicle should be evaluated with respect to the defined measure, and the acceptable level of performance.
2. Proposal of an assessment and approval procedure; in other words, a description of how an HCT vehicle should be assessed in accordance to the developed PBS. The assessment procedure can be formula-based calculations, simulations or full scale testing with instrumented vehicles. However, the ambition is to avoid full scale testing.
3. Proposal of an implementation method which includes guidelines on how to change the regulations and who would be responsible for assessment and approval of the vehicles, compliance monitoring and enforcement.
4. Identification of a number of HCT vehicles with high efficiency, low impact on infrastructure and safe performance as potential future HCTs. The proposed HCT vehicles should include combinations that are suitable for all the three application areas of HCT, namely bulky goods, medium-heavy goods and heavy goods transport.

The project started in November 2013 and is planned to be completed by the end of 2016. The first two work packages (out of 10) have been concluded so far, descriptions of which are presented in the following sections. During the project, inputs from an international advisory group will be collected to secure compliance with possible similar activities worldwide.

3. WP1 – Literature and State of the Art Review

The first work package was focused on the review of the existing standards and literatures on the performance of heavy vehicles. Three aspects of the heavy vehicles performance and corresponding measures/standards were studied:

1. Safety & manoeuvrability related measures with focus on minimizing risk for accidents and maximizing accessibility for the HCT vehicles.
2. Infrastructure related measures with focus on minimizing damage and wear on the pavements and bridges.
3. Environment related measures with focus on fuel consumption, exhaust emission and noise.

The safety and manoeuvrability related category was the main focus of the study.

3.1 Safety and Manoeuvrability Related Performance Measures

In this section the safety and manoeuvrability related performance measures, which were found in existing PBS approaches or studies on performance of heavy vehicles, are summarized. They are categorized into four groups based on the practical goals they address (adapted from the goals used by Fancher et al, 1989); the four groups are:

Table 1 - Safety and manoeuvrability measures and corresponding required level of performance in the PBS approaches in Australia, New Zealand and Canada (VWDS 1987, NTC 2008, LTSA 2010)

	Performance measure	Australia*	New Zealand	Canada
Traction	Startability	Achievable grade 15, 12, 10, 5 [%]	Same as Australia	-
	Gradeability	Achievable grade 20, 15, 12, 8 [%] Viable speed on 1% grade 80, 70, 70, 60 [km/h]	Same as Australia	-
	Acceleration capability	Travel time for 100 m 20, 23, 26, 29 [s]	Same as Australia	-
Tracking	Tracking ability on a straight path	swept width at 90 km/h 2.9, 3.0, 3.1, 3.3 [m]	Same as Australia	-
	Frontal swing	90° turn of 12.5 m radius 0.7 [m]	Same as Australia	-
	Tail swing	90° turn of 12.5 m radius 0.3, 0.35, 0.35, 0.5 [m]	Same as Australia	-
	Low-speed swept path (offtracking for Canada)	90° turn of 12.5 m radius 7.4, 8.7, 10.6, 13.7 [m]	120° turn of 12.5 m radius 7.6 [m]	90° turn of 11 m radius 6 [m]
	High-speed steady-state offtracking	-	100 km/h, 393m radius 0.6 [m]	100 km/h, 393m radius 0.46 [m]
	High-speed transient offtracking	ISO SLC, 88 km/h, 0.4 Hz 0.6, 0.8, 1.0, 1.2 [m]	Same as Australia	ISO SLC, 88 km/h, 0.4 Hz 0.8 [m]
Stability	Steady-state rollover threshold	0.35 [g]	0.35 [g]	0.4 [g]
	Load transfer ratio	-	ISO SLC, 88 km/h, 0.4 Hz 0.6 [-]	ISO SLC, 88 km/h, 0.4 Hz 0.6 [-]
	Rearward amplification	ISO SLC, 88 km/h, 0.4 Hz 5.7 SRT (lateral acc.)	Same as Australia	-
	Yaw damping coefficient	ISO 14791 - pulse input 0.15 [-]	Same as Australia	-
	Handling quality	Yet to be defined	-	-
	Friction demand of steer tyres in a tight turn	90° turn of 12.5 m radius 80%	Same as Australia	-
	Friction demand of drive tyres in a tight turn	-	-	90° turn of 11 m radius 0.1 (friction coefficient)
Braking	Braking efficiency	-	-	0.4 g braking 70%
	Braking stability on a straight path	60 km/h, 0.2-0.4g braking 2.9, 3.0, 3.1, 3.3 [m]	Same as Australia	-

*Four values for different level of access to the road network

- **Traction:** The heavy vehicle should be able to start motion, maintain motion and attain a desirable level of acceleration; measures that can be used to assess the vehicle performance with respect to these goals are listed in this group.
- **Tracking:** The rear end of the vehicle and all the units within the vehicle combination should follow the path of the front end of the vehicle with adequate fidelity; measures that can be used to assess the vehicle performance with respect to this goal are listed in this group.
- **Stability:** The vehicle should be stable, attain directional control and remain upright during manoeuvring; measures that can be used to assess the vehicle performance with respect to these goals are listed in this group.
- **Braking:** The vehicle should safely attain a desirable level of deceleration during braking; measures that can be used to assess the vehicle performance with respect to this goal are listed in this group.

The gathered performance measures within the four above-mentioned groups are summarized in Table 1. For each performance measure, the corresponding test manoeuvre and the required level of performance in the existing PBS in Australia, New Zealand and Canada are provided. Part of the braking performance measures are listed separately in Table 2, since the corresponding listed levels of performance are based on the EU and US regulations.

It should be noted that the possible associated risk with overtaking of long heavy vehicles and the required measures are not addressed in this project and a separate investigation is required. A study on overtaking of 30 m long HCT vehicles has been conducted by the Swedish road and transport research institute, VTI, which showed no significant risk; however, it was concluded that further field studies are required (Andersson, et.al, 2011).

Table 2 - Braking performance measures and corresponding required level of performance in the EU and the US regulations

Performance measure	**EU (ECE R13)**	**US (FMVSS 121)**
Braking deceleration/stopping distance	5 m/s^2 from 60 km/h 4 m/s^2 from 90 (80) km/h* 4 m/s^2 from 60 km/h (after 20 repeated braking from 60 to 20 km/h at 3 m/s^2) 3.3 m/s^2 from 60 km/h (after 6 km braking)	76.2 m from 96.5 km/h
Braking efficiency	75%, 50 km/h, friction coefficients of 0.3 & 0.8	-
Braking stability on a straight path	Subjectively, 4 m/s^2 braking from 90 (80) km/h*	-
Braking stability in a turn	-	3.7 m lane in a 152 m radius turn at 48.3 km/h
Braking stability on a split friction surface	SWA<240° (120°)**, kH>0.5, kH/kL>2, 50 km/h	
Parking ability on a grade	18 % slope, single vehicle, loaded up to GVW. 12 % slope, unbraked trailer, loaded up to GCW	20% slope

* Value in parenthesis is for tractors ** Value in parenthesis is for the first 2 seconds

3.2 Infrastructure Related Performance Measures

Limiting the axle loads, is a widely used approach for controlling the effect of heavy vehicles on pavements. In Sweden, the axle load limit depends on the bearing capacity (BK) of the road (three classes) and the axle configuration, see Table 3.

Table 3 – Axle load limits in Sweden

	BK1	**BK2**	**BK3**
1. Axle load			
a. Axle that is not a driving axle	10 t	10 t	8 t
b. Driving axle	11.5 t	10 t	8 t
2. Bogie load			
a. The distance between the axles is less than 1.0 m.	11.5 t	11.5 t	11.5 t
b. The distance between the axles is 1.0 m or more but not 1.3 m.	16 t	16 t	12 t
c. The distance between the axles is 1.3 m or more but not 1.8 m.	18 t	16 t	12 t
d. The distance between the axles is 1.3 m or more but not 1.8 m and the driving axle is fitted with twin wheels and pneumatic or equivalent suspension or the driving axles are fitted with twin wheels and the weight on no axle exceeds 9.5 t.	19 t	16 t	12 t
e. The distance between the axles is 1.8 m or more.	20 t	16 t	12 t
3. Triple axle load			
a. The distance between the outer axles is less than 2.6 metres.	21 t	20 t	13 t
b. The distance between the outer axles is 2.6 metres or more.	24 t	22 t	13 t

Table 4 – Examples of bridge formulae used for regulation of heavy vehicles loading

Country	**Bridge Formula**	**Notes**
Australia (NTC 2008)	Access to the PBS level 1 road network M = 3L + 12.5 for M <= 42.5 t M = L + 32.5 for M >= 42.5 t Access to the PBS level 2 road network M = 3L + 12.5 for M <= 46.5 t M =1.5L + 29.5 for M >= 46.5 t Access to the PBS Level 3-4 road network M = 3L + 12.5 for all M	L [m] = distance between the extreme axles of any two axle groups M [ton] = total gross mass on the axles within that distance L
United States (USDoT 2000)	W = 500 [L N / (N - 1) + 12 N + 36]	W [lb] = maximum weight on any group of two or more consecutive axles L [ft] = distance between the extremes of the axle group N = number of axles in the axle group
South Africa (SADoT 2009)	M1 = 2100 L + 18000 For abnormal load vehicles M2 = EW (6.850 + 0.00145 AD)	L [m] = distance between the centres of extreme axles of any two axle groups M1 [kg] = maximum combined mass on all the axles within the distance L M2 [kg] = Allowable maximum mass of the group of axles EW [mm] = Effective Width AD [mm] = Distance between the centre of the first axle of any group of axles to the centre of the last axle of the group

In the Australian PBS, in addition to the axle load limits, there are maximum limits on the gross mass of the vehicle and the tyre inflation pressure, in order to control the pavement horizontal loading and pressure distribution. It should be noted that the gross mass limits in the Australian PBS, which depend on the number of driving axles, are higher than the existing prescriptive regulations in Australia.

Bridges are another important part of the infrastructure which should be protected against excessive loading. Bridge formulae are widely used for estimating the effect of heavy vehicle loadings on bridges and advising some limits on the total mass based on the axle configurations. In Table 4, some examples are provided.

3.3 Environment Related Performance Measures

The existing regulations on heavy vehicles with respect to exhaust emissions, fuel consumption and noise emissions were reviewed. The outcome of the review is briefly described here.

Exhaust Emissions

The common way of regulating exhaust emissions of heavy vehicles is to specify limits for the gaseous and particulate pollutants in the exhaust gas. In comparison to passenger cars and light duty vehicles where emission limits is distance based (per km), emission regulations for heavy vehicles worldwide is engine-based and the emission limits are expressed per produced work (per kWh) in a given test. The main reason for this approach is that heavy vehicles are produced in smaller numbers but in great numbers of variants. Therefore the type approval for emissions is related to the engine which can be installed in different vehicle configurations.

As an example, the emission limits in Euro VI are listed in Table 5. Euro VI is the common term used to refer to the exhaust emission regulation for heavy vehicles in Europe, stated in EU regulation No 595/2009. Euro VI has been in effect since 31 Dec 2013 for all new engines. Euro VI regulation additionally includes limits on off-cycle emissions (OCE) and Portable Emission Measurement System (PEMS) procedure for in-use emission testing.

Table 5 - Euro VI emission limits

	CO (mg/kWh)	THC (mg/kWh)	NMHC (mg/kWh)	CH_4 (mg/kWh)	NO_X (mg/kWh)	NH_3 (ppm)	PM mass (mg/kWh)	PM number (#/kWh)
Compressed Ignition (WHSC)	1500	130			400	10	10	8.0×10^{11}
Compressed Ignition (WHTC)	4000	160			460	10	10	6.0×10^{11}
Positive Ignition (WHTC)	4000		160	500	460	10	10	6.0×10^{11}

WHSC: World Harmonized Steady state Cycle, WHTC: World Harmonized Transient Cycle, 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

Fuel Consumption

Unlike for passenger cars and light duty vehicles, no fuel consumption/CO_2 regulation for heavy vehicles is in effect in Europe yet. However, the Commission has recently set out strategy to curb CO_2 emissions of high duty vehicles and has developed a test procedure to measure their fuel consumption and CO_2 emissions. The developed test procedure is based on tests of the individual components of the vehicle and simulations of the fuel consumption and CO_2 emissions of the entire vehicle (UniGraz 2012).

In the US regulation for fuel consumption, differentiated standards are adopted for nine sub-categories of combination tractors based on three attributes: weight class, cab type and roof height. The standards include CO_2 limit and fuel consumption limit which are identical based on an emission factor (EPA 2011). Japan also has a regulation for fuel consumption of heavy vehicles, called the TRIAS, which has already been published in 2007. However, the standards will be in effect form April 2015. The test procedure in TRIAS is a combined engine testing and vehicle simulation where the engine testing provides input data for the simulation model.

Noise Emissions

The vehicle noise regulation in EU are stated in directive 70/157/EEC which are similar to the UNECE Regulation 51. In these regulations, the procedure for measuring the vehicle noise is based on ISO 362:1998 pass-by-noise standard. For heavy vehicles, the noise is measured with the vehicles accelerating with wide open throttle with an approach speed of 50 Km/h.

The ISO 362 Standard has been revised in 2007 with the objective of attuning to real-life situations. Following the ISO 362 revision, discussions have been going on to also revise Regulation UN51 which has resulted in a new proposal. The new proposal is being considered by the EU and the new revision of EU directive is expected to be published in 2014. The new proposal for vehicle noise regulations adopts the ISO 362:2007 as the testing procedure and proposes new noise limits to be implemented in 3 phases, see Table 6.

The UN51 regulation has been adapted in most of the member countries, the significant exceptions are the USA and Canada, who have their own testing standards and limits. In the USA regulations, the SAEJ366 pass-by-noise test is used, which includes both an acceleration test and a deceleration test.

In addition to the vehicle noise, there are regulations limiting the tyre noise which is the major noise source for heavy vehicles at speeds higher than 50 km/h. The current noise limits for heavy vehicle tyres in Europe, stated in EC 661/2009, are presented in Table 6.

Table 6 – Noise limits of the heavy vehicles and their tyres in the EU regulations

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

*Limits for the three phases **An additional 1db is allowed for winter tyres

4. WP2 – Selecting a preliminary set of performance measures

In work package 2 a list of selection criteria were prepared, based on which discussions were held to decide which one of the gathered performance measures in work package 1 should be included in the preliminary set of performance measures to be investigated thoroughly in this project. The selection criteria are:

- They shall be valid with respect to the traffic issues of heavy vehicles
- Preferably, they shall be based on existing standards
- They shall be simple and robust
- They shall be measurable in full-scale vehicle tests
- They shall be compatible with European regulations
- Redundancy shall be avoided (with respect to the traffic issue to be captured)

For the measures in the traction, tracking and stability categories, it was concluded that all the listed measures in Table 1 should be considered for further investigation, except handling quality which reckoned not to have a robust definition and not to be directly related to safety hazards or a specific issue for HCT vehicles. It is anticipated that some of the listed measures are highly correlated; however, this should be verified by the investigation results, before a measure can be eliminated. The anticipated correlated measures are:

- High speed steady-state offtracking and the tracking ability on straight path; the difference is the level of lateral acceleration the vehicle is exposed to.
- Rearward amplification, load transfer ratio and high speed transient offtracking; rearward amplification of both lateral acceleration and yaw rate will be investigated.
- Startability, gradeability and acceleration capability

Furthermore, frontal swing, tail swing and low-speed offtracking will be investigated in the same manoeuvres, and if possible, will be replaced by one measure which cover all aspects of cornering at low speed. The manoeuvres will be based on the Swedish road characteristics.

For the measures addressing the braking performance of the heavy vehicles, it is reckoned that the existing measures in ECE R13 regulations are suitable for the HCT vehicles and only braking stability in a turn, which does not exist in the ECE R13, will be included in the upcoming investigations. However, to verify the suitability of ECE R13 regulation for HCT vehicles, some braking tests with a selection of HCT vehicles should be conducted to verify that certifying each unit separately, which is the case in ECE R13, is sufficient to assure an acceptable braking performance of the complete vehicle.

An important aspect of the study is to investigate each of the preliminary selected measures with respect to both high and low friction surfaces, where tyre characteristics and tyre modelling play an important role. Existence of correlations between the performance on high and low friction surfaces will be investigated.

5. Future work

The outcome of WP1 and WP2 is a preliminary list of performance measures which should be further investigated to verify their suitability for Swedish conditions. A performance measure is the first constituent part of a performance based standard, the other two parts, the corresponding test manoeuvre and the acceptable level of performance, will be determined in the continuation of the project by extensive studies in form of test track experiments and offline simulations. The Swedish road network will be categorized to be able to propose different levels of required performance, based on the level of access to the road network, similar to the Australian approach.

Furthermore, driving simulator studies will be conducted in order to be able to analyse the performance of the HCT vehicles in real traffic situations and different road conditions. By driving simulator studies, it will be possible to relate the driver's perception of the vehicle performance and stability with the defined performance measures. Moreover, possible driver adaptation to the vehicle performance will be investigated.

WP2 was focused on the safety and manoeuvrability related PBS; the infrastructure and environment related PBS will be addressed later in the project. The main questions are:

- Is complying with the existing axle load limits sufficient to ensure that HCT vehicles will not have negative effects on the pavements?
- Is it applicable to use a bridge formula to assess the effect of an HCT vehicle on the bridges?
- Are the existing regulations on the exhaust emissions and prospective ones on the fuel consumptions suitable for HCT vehicles as well?
- Should the tyre noise limits be different for HCT vehicles due to the fact that a long heavy vehicle combination is equipped with more tyres?

Throughout the project, based on the outcomes of the conducted studies, performed simulations and test track experiments, a number of safe and eco-friendly HCT vehicle types with low impact on infrastructure will be identified, considering market needs and transport efficiency aspects. Finally, a regulatory frame work for Sweden, including an assessment procedure and an implementation method, will be proposed.

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