

**PERFORMANCE BASED STANDARDS PROJECT IN SWEDEN**



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**Abstract**

There is a great interest in increasing the efficiency of the transport system in Sweden, which makes the High Capacity Transports (HCT) an attractive solution. To gain more knowledge about HCT vehicles and their effects on traffic safety, infrastructure and environment, the Swedish government is undertaking a large research program focused on HCT vehicles in Sweden. One of the projects in the HCT program was “Performance based standards for high capacity transport in Sweden”. This project started at the end of 2013 to investigate the applicability of a regulatory framework based on performance based standards in Sweden, taking into consideration the winter road conditions. This paper presents a summary of the main outcomes of the project, which ended in 2017.

**Keywords:** High productivity vehicles, standards and regulations, performance measures, assessment procedures

## **1. Introduction**

The existing legislation in Sweden, allows heavy vehicle combinations with maximum length of 25.25 m and maximum weight of 64 t, based on the European modular system. However, from April 2018, heavier vehicles up to 74 t has been allowed on a designated part of the road network. To gain more knowledge about HCT vehicles and their effects on traffic safety, infrastructure and environment, the Swedish government is undertaking a large research program focused on HCT vehicles in Sweden. One of the projects in the HCT program is “Performance based standards for high capacity transport in Sweden” (Kharrazi et. al. 2014).

Performance Based Standards (PBS) is a way of regulating HCT vehicles and their access to the road network. Under a PBS approach, standards would specify the performance required from the vehicle operations rather than mandating prescriptive length and weight limits. The inherent flexibility in the PBS approach allows development of innovative vehicles optimized for different applications, without negative effects on safety, infrastructure and environment. PBS for regulation of heavy vehicles has been implemented in Australia (NTC 2008), Canada (Woodrooffe et. al. 2010), and New Zealand (De Pont et. al. 2016). It is also under trial in South Africa (Nordengen and Steenkamp 2016).

The PBS project in Sweden started at the end of 2013 to investigate the applicability of PBS in Sweden and to identify a set of performance based standards suitable for Sweden, with attention to winter road conditions. The project ended in September 2017. This paper provides a summary of main outcomes of the PBS project.

## **2. Research Approach**

In the PBS project, all the three aspects of infrastructure, environment and safety were investigated, but the focus was on safety. The infrastructure aspects, which were focused on road network categorization with respect to 74t vehicles, was mostly performed by Swedish Transport Administration, results of which has been published as a public report (Trafikverket 2016).

All the existing regulations with respect to environmental aspects of heavy vehicles are already performance based; thus, proposing new standards for HCT vehicles was deemed to be unnecessary. However, to address the concerns about the noise emissions of HCT vehicles, a short study was performed on simulation and comparison of noise emissions of a conventional and an HCT vehicle. The simulation results showed that the noise emission from the HCT vehicles is slightly higher than the conventional vehicle, per vehicle passage; however, for a certain transportation task, the number of vehicles in traffic will be lower using HCT vehicles. Thus, the resulting road traffic noise exposure is very similar (Sandberg et. al. 2018).

During the PBS project extensive research were performed on safety aspects of HCT vehicles. It started with reviewing the relevant literature and existing PBS schemes and regulations of heavy vehicles in different countries, which resulted in a candidate set of performance measures for further investigation. The selected measures for further investigation were mainly focused on traction, tracking and stability; since it was reckoned that the existing measures with respect to braking performance in ECE R13 regulations are suitable for the HCT vehicles as well. For more information about the state of the art review and the candidate measures, see (Kharrazi et. al. 2015).

To study the candidate performance measures and their relevancy for assessing heavy vehicles performance, a representative fleet of heavy vehicles with 22 vehicles, including both prospective HCT vehicles and existing conventional heavy vehicles on Swedish roads, was selected. All the selected vehicles were modelled to simulate the performance of the representative fleet. Moreover, tests with a subgroup of the representative fleet were performed on the test track to further investigate the performance of the vehicles and to gather data for validation of the models. In the following sections some of the conducted studies in the project are briefly presented.

## **2.1 Driving Simulator Study**

A driving simulator study with 54 professional truck drivers was performed to evaluate and compare the performance of HCT and conventional vehicles in realistic driving conditions. Furthermore, correlation between driver subjective evaluation of the vehicle performance and the objective performance measures was investigated.

Each participant in the simulator study drove a pair of vehicles consisting of an HCT vehicle and a conventional vehicle. The three chosen vehicle pairs were:

- Tractor-semitrailer & Adouble
- Nordic & ABdouble
- Truck-centre axle trailer & Truck-double centre axle trailers

The vehicle combinations were parameterized in a way that the vehicles in one of the pairs, namely the Nordic and ABdouble, had a similar performance with respect to lateral dynamics, although the ABdouble was longer and heavier, see Table 1.

**Table 1 - Performance of the vehicles of the simulator study in a lane change with 0.3 Hz single sine steer input, resulting in a lateral acceleration of 1.5 m/s<sup>2</sup> at the front axle**

	<b>TR-ST</b> <b>40 t, 16.5 m</b>	<b>TR-ST-DY-ST</b> <b>(Adouble)</b> <b>80 t, 30 m</b>	<b>TK-DY-ST</b> <b>(Nordic)</b> <b>40 t, 19 m</b>	<b>TK-DY-LT-ST</b> <b>(ABdouble)</b> <b>74 t, 28 m</b>	<b>TK-CT</b> <b>64 t, 25 m</b>	<b>TK-CT-CT</b> <b>83 t, 32 m</b>
<b>Yaw rate RA</b>	1.08	1.84	1.65	1.65	1.31	2.12
<b>HSTO (m)</b>	0.29	0.92	0.88	0.95	0.49	1.29
<b>LTR (%)</b>	39	60	57	52	52	89

The drivers were asked to compare the controllability of the vehicles they drove by the question: “how easy/difficult it is to drive the HCT vehicle in comparison with the conventional vehicle”. It was a 7-grade scale question with 1 being much easier and 7 much more difficult. The results are presented in Table 2 . The drivers’ ratings show that an HCT vehicle is not necessarily more difficult to drive than a conventional vehicle. For instance, for the ABdouble and Nordic pair, which were parameterized to have similar performance, the drivers’ ratings also indicate that they are almost equally controllable. For the other two pairs, the drivers have rated the HCT vehicle to be slightly more difficult to drive, compared with the conventional vehicle. This is aligned with the fact that in those pairs, the HCT vehicle has significantly larger rearward amplification, offtracking and load transfer ratio.

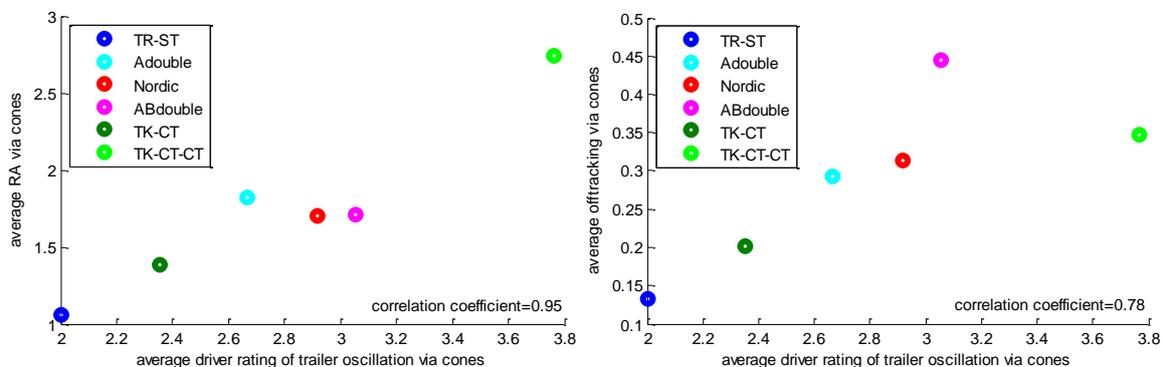
**Table 2 - Comparison of controllability of the HCT and conventional vehicles by drivers**

	<b>Adouble vs. Tractor-Semi</b>	<b>ABdouble vs. Nordic</b>	<b>Truck-CAT vs. Truck-double CAT</b>
Average rating, 1-7 scale	4.8 (slightly more difficult)	3.7 (almost the same)	4.9 (slightly more difficult)

Using the logged vehicle states in the simulator, offtracking, yaw rate rearward amplification and load transfer ratio of the vehicles during the performed manoeuvres by the truck drivers were calculated. Additionally, the drivers were asked to rate (in a 7-grade scale) different aspect of the vehicle performance during the driving scenario with questions such as:

- How easy it is to keep the vehicle on the desired path on the curvy parts of the road.
- How they perceive the roll stability of the vehicle on the curvy parts of the road.
- How they perceive the trailers, stable or oscillatory, during overtaking and lane changes.
- How easy it is to control the vehicle.

The obtained results showed that there is a strong correlation between drivers' perceived performance and the calculated objective performance measures. A sample result is shown in Figure 1.



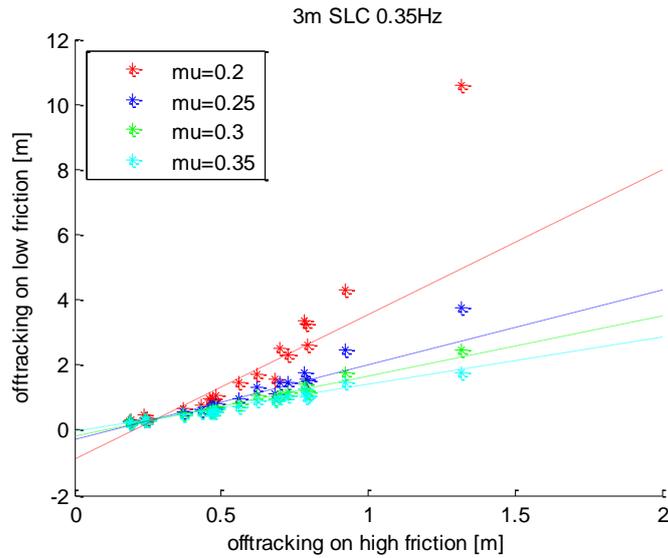
**Figure 1. Correlation between yaw rate rearward amplification and offtracking with drivers' ratings of trailer oscillations during double lane change manoeuvres, a lower rating by drivers means better performance.**

## 2.2 Heavy vehicle performance, winter vs summer

One of the key issues investigated in the PBS project was the correlation between performance of the selected representative in summer and winter. The results of these correlation studies can be used to assign required performance levels which ensure safe performance both under summer and winter conditions.

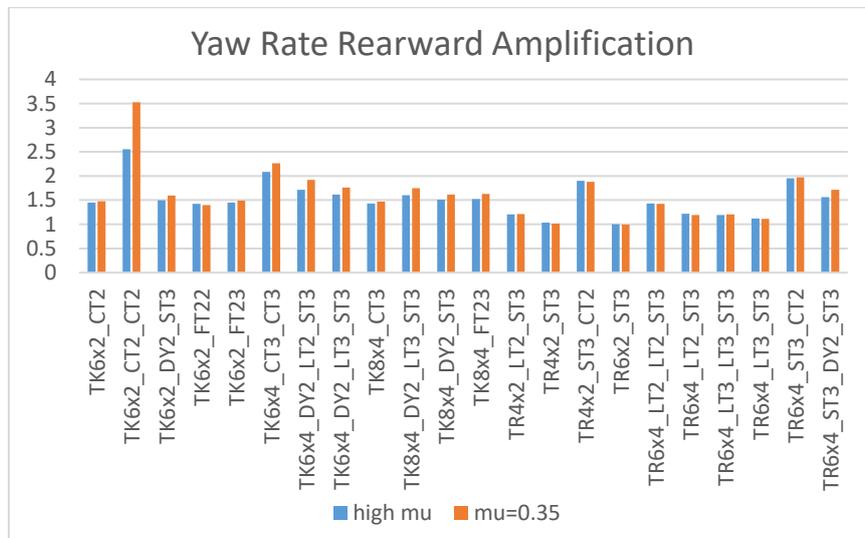
For instance, the offtracking of the reference fleet in a 3 m open loop single lane change manoeuvre is illustrated in Figure 2; speed of 80 km/h is used for high friction and 70 km/h for low friction. Considering the linear correlation depicted in Figure 2, the low friction ( $\mu=0.35$ ) offtracking is about 1.45 times more than the high friction offtracking. Thus, the offtracking in summer should be below 0.7 m, in a single lane change at 80 km/h with lateral displacement of 3m, to ensure an offtracking below 1.0 m in winter, which means the vehicle stays within the lane on major roads in winter as well, considering a lane width of 3.5 m and

the vehicle width of 2.5 m. Another approach can be to reduce the allowed speed of the vehicles in winter condition so that the resulting offtracking will be comparable with the offtracking in summer at speed of 80 km/h.



**Figure 2 - Correlation between offtracking of the vehicle combinations in the reference fleet in winter versus summer, during a 3 m SLC manoeuvre for different friction levels.**

Figure 3 shows that the rearward amplification of yaw rate for winter and summer are highly correlated. Although the values for winter and summer are not too different, the difference gets exaggerated for vehicles with poor performance which will result in swing out and instability in winter. Thus, the yaw rate rearward amplification in summer condition should be below a certain value, to ensure that the vehicle will not be prone to yaw instability in winter. All the simulated vehicle combinations have a yaw rate rearward amplification below 2.1, except for the vehicle combination with double two-axled centre axle trailers.



**Figure 3 - Yaw rate rearward amplification of vehicle combinations in the reference fleet in a 3 m SLC manoeuvre in winter and summer**

The traction measures, namely startability, gradeability were also investigated in summer and winter. The calculations were performed at Volvo using a detailed powertrain model. Less vehicles were considered in this study compared to the reference fleet, since the effect of axle configuration of the towed units on the traction measures is insignificant; the key factor is the normal load on the driven axles. The simulation results showed that the effect of tyre-road friction level on the gradeability is insignificant. However, the startability of the heavy vehicles deteriorate significantly with lower friction levels; on average the calculated startability on a low friction surface is only 10% of the startability on a high friction (with a 750 hp engine), see Figure 4.

None of the considered heavy vehicle combinations, not even the conventional vehicles, will be able to start on a grade higher than 5% when the tyre-road friction level is low. This is far from 12% which a heavy vehicle combination should be able to start on during summer conditions. One solution to overcome the startability issue of the heavy vehicles in winter is to allow exceeding the driver axle load limit during a brief time at start up, by axle lift or other means of load transfer to drive axles.

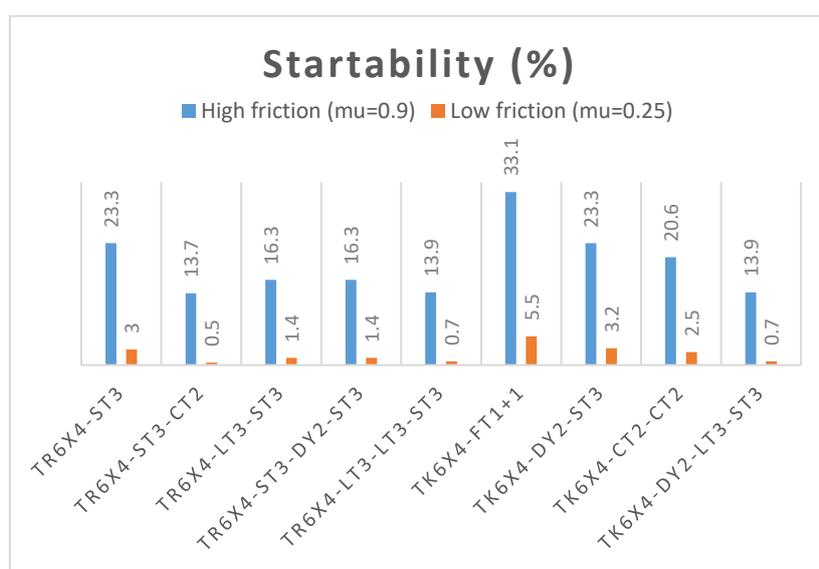


Figure 4 - Effect of tyre-road friction level on the startability

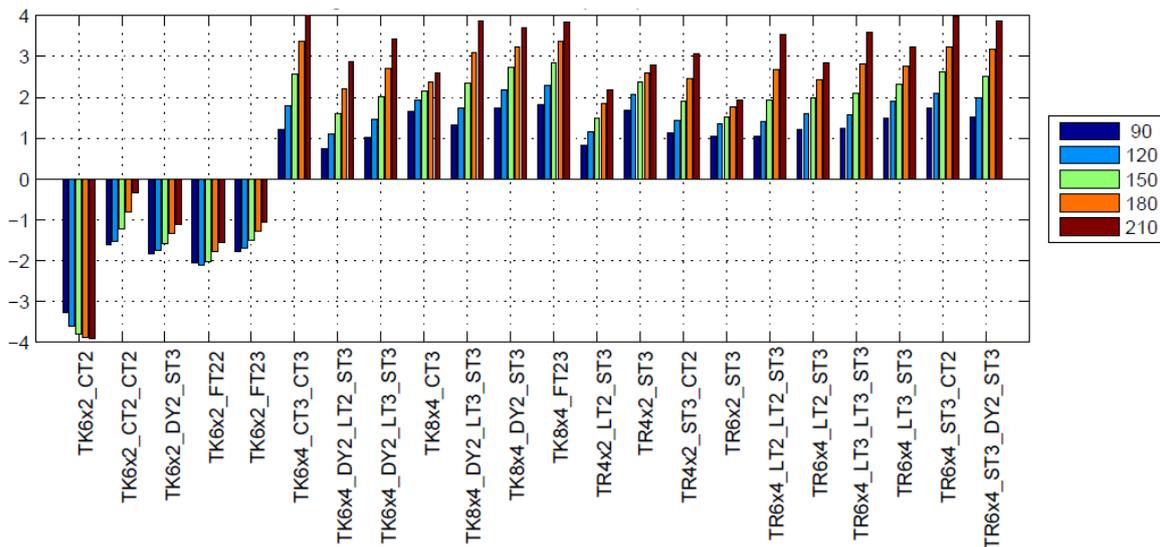
### 2.3 Assessment procedure

Another subject studied in the PBS project was the required level of modelling details for assessing performance of heavy vehicles with respect to the candidate measures. The simplicity of the models used to assess the performance measures decrease the risk of inaccurate and erroneous results due to incorrect parameters and other mistakes in the model. It would also increase the user understanding and potentially make the processes and routines in the legislations simpler. However, it is of importance that the accuracy of the model output is high enough to claim that it can assess the effect of the vehicle on the safety.

For traction measures, three levels of model complexity were investigated and compared. The most comprehensive model was an OEM developed model. The second level was a model taken from Kati et. al. (2014) which makes use of an engine map, considering effects of rotating parts, but neglects time delays in gear shifting. The third and simplest model, derived

in the PBS project, was not a simulation model, but simple expressions dependent on the most influencing components such as the maximum torque that the engine can produce. The comparison results showed that the simple expression could potentially be used for assessment of heavy vehicles performance with respect to traction measures, for more information see (Bruzelius et. al. 2016).

Additionally, a simple model for calculation of the swept path in a low speed turning manoeuvre was derived in the PBS project. The simple model generates the trajectory of the wheels, often called tractrix. The relative error of the simple expression with respect to the vehicle models are illustrated in Figure 5. The relative difference between the two are less than 4% for all vehicle combinations and simulated turn angles.



**Figure 5 - Relative difference in percentage between swept path calculated by the tractrix expression and the multibody dynamics models**

The required level of model complexity for high speed performance measures was also investigated. For this purpose, the developed high-fidelity models were compared with a simpler yaw-plane single track linear model. The early analysis showed that inclusion of the tyre relaxation length has a significant effect, and that the validity of the single track linear model deteriorates considerably without it. Thus, the tyre relaxation length was included in the linear model as well.

The analysis was performed on three vehicle combinations, a truck-hauling two centre axle trailers, and Nordic and Adouble combinations. The results showed that the estimation error for the yaw rate rearward amplification by the simple model is less than 15% for most cases, so a 2D model might be sufficient for calculation of this measure. However, the estimation error for yaw damping ratio can be more than 20% and the estimation errors for high speed transient offtracking and load transfer ratio are substantial. Thus, a three-dimensional model is needed for calculation of these measures.

For more information about the results of model complexity investigation, refer to the final report of the PBS project (Kharrazi et. al. 2017).

### **3. Conclusions**

During the PBS project extensive research were performed on safety aspects of HCT vehicles resulting in a proposal of a PBS scheme, using test track experiments, offline simulations and driving simulator studies.

The driving simulator study showed that there is a strong correlation between drivers' perceived performance and controllability of the vehicles with the performance measures investigated in the study. Furthermore, the study results indicated that controlling and driving an HCT vehicle does not need more effort than driving a conventional heavy vehicle, if the vehicles have similar performance values. The driving simulator study results confirmed that using a PBS scheme for assessing heavy vehicles is a better approach for ensuring their safe performance than limiting their length and weight.

One of the main objective of the PBS project was to investigate the applicability of PBS in Sweden with attention to winter road conditions. Thus, the safety aspects which should be considered with respect to winter conditions were investigated, resulting in proposals for safe performance levels. Moreover, the required complexity of models for accurate assessment of heavy vehicles with respect to the performance measures in the proposed PBS scheme were identified. More detailed information about the outcome of the PBS project can be found in the final report of the project which is publicly available (Kharrazi et. al. 2017).

There is still a need for further studies with respect to PBS for HCT vehicles in Sweden. One important aspect which needs further investigation is the effect of tire characteristics on the performance of the HCT vehicles. Due to the existing variety of tires and the diversity of road surface condition, especially during winter, choosing one tire for assessing HCT vehicles is not a trivial task. Therefore, there is a need for defining and modelling standard tires to be used in assessment of HCT vehicles with respect to a Swedish PBS scheme. To do so, the existing range of truck tires in the market should be analyzed, compared and categorized so that one or more representative tires can be selected and modelled as standard tires.

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*HVTT15: Performance based standards project in Sweden*

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