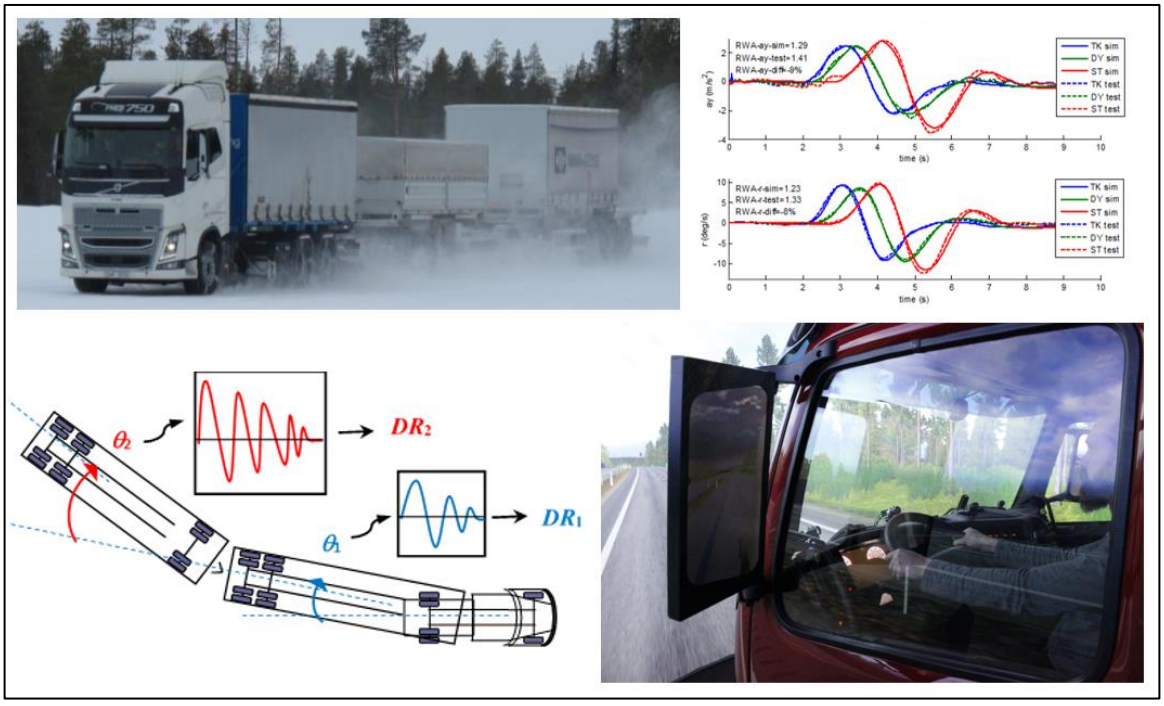
# Performance based standards for high capacity transports in Sweden

**Public report**





Project within FIFFI, Integrated vehicle and infrastructure development in FFI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# Content

# 1. Summary

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 in Sweden, which makes the High Capacity Transports (HCT) an attractive solution. 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 approach is to use performance based standards (PBS) for regulation of heavy vehicles access to the road network; under a PBS approach to regulation, standards would specify the performance required from vehicle, rather than mandating limits on the vehicle length or weight. In this scope, the project "Performance Based Standards for High Capacity Transports in Sweden" started at the end of 2013 to investigate applicability of PBS in Sweden. The purpose of the project is to propose a regulatory framework based on PBS by identifying a set of performance based standards suitable for Sweden.

The project started by reviewing the relevant literature and existing PBS schemes and regulations of heavy vehicles in different countries. Based on the review results a candidate set of performance measures for further investigation, with respect to the Swedish conditions, was identified. Correlation between HCT vehicles performance during winter and summer with respect to these measures have been studied, using simulations and experiments on test track. Furthermore, different assessment procedures and required model complexity for evaluation of HCT vehicles performance have been studied and proposals have been provided for a regulatory framework. The end results of the project are gathered in the VTI report 948A with the title: "Performance based standards for high capacity transports in Sweden – FIFFI project 2013-03881 – Final report".

# 2. Sammanfattning på svenska

Transportsektorn står inför stora utmaningar när det gäller att minska energiförbrukning och miljöpåverkan. Ett attraktivt alternativ för att effektivisera transportsystemet i Sverige är att öka kapaciteten hos tung trafik genom att tillåta längre och tyngre fordon, på engelska kallade High Capacity Transport (HCT) fordon. För att kunna introducera HCT-fordon i Sverige så behöver regelverk och föreskrifter utvecklas på ett sätt som säkerställer att ett certifierat HCT-fordon inte får negativa effekter på trafiksäkerhet, infrastruktur och miljö. En variant för att reglera tunga fordons tillträde till vägnätet är att använda prestandabaserade kriterier, eller Performance Based Standards (PBS). Vid prestandabaserade föreskrifter så specificeras kriterier eller standarder för en prestandanivå som ett fordon måste uppfylla, istället för att bestämma hur samma prestandanivå skulle uppnås genom att sätta gränser för fordonets längd eller vikt. För att utreda möjligheterna till en introduktion av PBS i Sverige så startade projektet "Performance Based Standards for High Capacity Transports in Sweden" i slutet av 2013.

Syftet med projektet är att föreslå ett prestandabaserat regelverk för HCT-fordon och deras tillträde till vägnätet i Sverige.

Projektet inledde med en granskande genomgång av befintlig relevant litteratur, föreskrifter och prestandabaserade lösningar för tunga fordon i olika länder. Baserat på genomförd granskning identifierades en uppsättning av prestandabaserade mått för vidare utredning med hänsyn till svenska förhållanden och vinterväglag. Korrelationer mellan fordonsprestanda vid körning på hög och låg friktion, med avseende på dessa mått, har studerats med hjälp av simuleringar och experiment på provbana. Vidare har olika utvärderingsmetoder och nödvändig modellkomplexitet för utvärdering av HCT-fordonets prestanda studerats. Slutresultatet av projektet samlas i VTI-rapport 948A med titeln: "Performance based standards for high capacity transports in Sweden – FIFFI project 2013-03881 – Final report".

# 3. Background

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 road; an alternative which is also expected to result in significant economic benefits. HCT refers to introduction of heavy vehicle combinations with higher capacity (longer and/or heavier vehicles) than the existing vehicles on the roads. With HCT vehicles, the existing capacity in the road infrastructure can be utilized efficiently without requiring too high investments, and the goods can be transported with fewer vehicles. It is expected that this will result in a reduction in the transport cost, fuel consumption, emissions and the traffic congestion.

The existing legislation in Sweden, allows heavy vehicle combinations with maximum length of 25.25m and maximum weight of 64t. However, the government is considering allowing heavier vehicles up to 74t on a designated part of the road network, which will be classified as a new category of roads with higher bearing capacity. The new road class, BK4, will be added to the existing three classes with bearing capacities BK1-3. Dispensations of longer and heavier HCT vehicles for trial periods have been granted in the recent years, which have shown considerable CO2-reduction, fuel saving and improved transport economy. According to Skogforsk website as of autumn 2017, 50 vehicles have been operating in the dispensation program, saving about 10 million litres of diesel and 25000 tons of CO2, since 2009.

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 the “Performance based standards for high capacity transport in Sweden” project. 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, Canada, and New Zealand, and is under trail in South Africa.

# 4. Purpose, research questions and method

The project "Performance based standards for high capacity transport in Sweden" started at the end of 2013 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. In the PBS project all the three domains of safety, infrastructure and environment were addressed; but, the focus has been on safety and manoeuvrability, for which extensive testing, simulations and analysis were conducted.

The project started by reviewing the relevant literature and existing PBS schemes and regulations of heavy vehicles in different countries. Based on the review results a candidate set of performance measures for further investigation was identified. To study the candidate performance measures and their relevancy for assessing heavy vehicles performance, a representative fleet of heavy vehicles, including both prospective HCT vehicles and existing conventional vehicles on Swedish roads, was selected and modelled. The performance of the selected representative fleet with respect to candidate measures, both in summer and winter was investigated using simulation and experiments on test track.

# 5. Objective

The project objective was formulated in a four bullets list in the application to Vinnova:

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, the acceptable performance level and, if applicable, a test maneuver during which the performance of the vehicle should be measured.
2. Proposal of an assessment and approval procedure; in other words, a description of how a 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 how the regulations should be changed, who is 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.

All the project objectives have been addressed in the project. However, the focus has been on the first two listed objectives. There have been parallel projects in the Swedish HCT program addressing different approaches to compliance monitoring and identification of safe and efficient HCT vehicles. Collaboration and exchange of knowledge with these projects have been pursued during the PBS project via the HCT program.

# 6. Results and deliverables

A review of regulations of heavy vehicles in Sweden and other regions, exiting PBS schemes in different countries and relevant literature on accidents, safety, infrastructure and environmental aspects of heavy vehicles was conducted. The review results are published as a VTI report (VTI report 859A).

Based on the review results a candidate set of performance measures for further investigation with respect to Swedish conditions was identified. The candidate measures, are grouped based on the practical goals they address and listed in Table 1.

To study the candidate performance measures and their relevancy for assessing heavy vehicles performance, a representative fleet of heavy vehicles, including both prospective HCT vehicles and existing conventional vehicles on Swedish roads, was selected, see Table 2. The vehicles in the representative fleet were modelled using the Volvo vehicle model library and validated against data gathered on test track.

Extensive simulations and experiments on test track were performed to study performance of the selected representative fleet with respect to candidate measures, both in summer and winter. The simulation results were used to study the correlation between heavy vehicles performance during winter and summer. The identified correlation can be used to assign required performance levels which ensure safe performance under both summer and winter conditions. For more information on the obtained results, refer to the VTI report on the end results of the PBS project (VTI report 948A).

Furthermore, the correlation between the candidate performance measures and the drivers' perception of the vehicle performance was investigated in a driving simulator study. More than 50 professional truck drivers drove HCT vehicles and conventional heavy vehicles in the VTI driving simulator and compared their performance. The study results revealed that the objective measures of the heavy vehicle lateral performance and stability used in a PBS scheme correlates to the driver perception of the vehicle performance. More details can be found in the VTI report on the end results of the PBS project (VTI report 948A).

*Table 1. Candidate performance measures, identified in the beginning of the PBS project*

| | **Performance measure** | **Description** |
|---|---|---|
| Traction | Startability | The maximum grade of the road on which the vehicle can commence from a standing start |
| | Gradeability | The maximum grade of the road on which the vehicle can maintain an acceptable speed |
| | Acceleration capability | The clearance time of the vehicle accelerating from standing still |
| Low speed tracking | Frontal swing | Swing out of the vehicle's front corner in a low speed tight turn |
| | Tail swing | Swing out of the vehicle's rear corner in a low speed tight turn |
| | Low-speed swept path | Total road width utilized by the vehicle in a low speed tight turn |
| High speed tracking | Tracking ability on a straight path | Total road width utilized by the vehicle responding to the road unevenness, on a straight path at high speed |
| | High-speed steady-state offtracking | The maximum distance between path of the rearmost axle of the vehicle and the prescribed path in a steady turn at high speed |
| | High-speed transient offtracking | The maximum distance between path of the rearmost axle of the vehicle and the prescribed path in a lane change at high speed |
| Low speed stability | Friction demand of steer tyres in a tight turn | Demanded friction at the steer tyres for maintaining the desired path in a low speed tight turn, indicating the proximity of loss of steerability |
| | Friction demand of drive tyres in a tight turn | Demanded friction at the drive tyres for maintaining the desired path in a low speed tight turn, indicating the proximity of a jackknife |
| High speed stability | Steady-state rollover threshold | The maximum steady lateral acceleration the vehicle can withstand before rolling over |
| | Load transfer ratio | The fractional change in the load carried on the left and right tyres in a lane change at high speed, indicating the proximity of a lift off |
| | Rearward amplification | Amplification of motion (lateral acceleration or yaw rate) in rear units of the vehicle in a lane change at high speed |
| | Yaw damping coefficient | The rate at which the yaw oscillations of the vehicle settle after a pulse steer input at high speed |
| Braking | Braking stability in a turn | Directional stability and controllability of the vehicle under heavy braking in a turn |

*Table 2. Representative fleet*

| No | Axle configuration* | Dimension | Heavy Vehicle Combination |
|---|---|---|---|
| 1 | TR4x2-ST3 | 16.5m, 40t | Tractor-Semitrailer |
| 2 | TR6x2-ST3 | 17.1m, 50t | |
| 3 | TR4x2-LT2-ST3 | 24.8m, 60t | Tractor-Link trailer-Semitrailer (Bdouble) |
| 4 | TR6x4-LT2-ST3 | 25.4m, 70t | |
| 5 | TR6x4-LT3-ST3 | 25.4m, 74t | |
| 6 | TR4x2-ST3-CT2 | 25.1m, 60t | Tractor-Semitrailer-Centre axle trailer |
| 7 | TR6x4-ST3-CT2 | 25.7m, 70t | |
| 8 | TR6x4-ST3-DY2-ST3 | 31.1m, 80t | Tractor-Semitrailer-Dolly-Semitrailer (Adouble) |
| 9 | TR6x4-LT2-LT2-ST3 | 33.7m, 90t | Tractor-Link trailer-Link trailer-Semitrailer (Btriple) |
| 10 | TR6x4-LT3-LT3-ST3 | 33.7m, 98t | |
| 11 | TK6x2-CT2 | 18.8m, 40t | Truck-Centre axle trailer |
| 12 | TK8x4-CT3 | 19.9m, 56t | |
| 13 | TK6x2-FT2+2 | 24.1m, 60t | Truck-Full trailer |
| 14 | TK6x2-FT2+3 | 24.1m, 64t | |
| 15 | TK8x4-FT2+3 | 25.1m, 74t | |
| 16 | TK6x2-DY2-ST3 | 24.1m, 64t | Truck-Dolly-Semitrailer |
| 17 | TK8x4-DY2-ST3 | 25.2m, 74t | |
| 18 | TK6x2-CT2-CT2 | 27.6m, 64t | Truck-Centre axle trailer-Centre axle trailer |
| 19 | TK6x4-CT3-CT3 | 28.4m, 74t | |
| 20 | TK6x4-DY2-LT2-ST3 | 32.4m, 80t | Truck-Dolly-Link trailer-Semitrailer (ABdouble) |
| 21 | TK6x4-DY2-LT3-ST3 | 32.4m, 92t | |
| 22 | TK8x4-DY2-LT3-ST3 | 33.5m, 98t | |

Another issue studied in the PBS project was the required level of modelling details for assessing performance of heavy vehicles with respect to different measures. It was shown that for traction measures and low speed tracking measures, listed in Table 1, simple expressions can be used without a significant loss in accuracy. The model complexity for high sped tracking and stability was also investigated which showed that a 2D yaw-plane model cannot provide accurate enough estimation of the vehicle performance, and inclusion of the roll dynamics is important.

The studies conducted on assessment models and procedures led to early steps toward development of a PBS tool for evaluation of heavy vehicles performance, which is an important part of a PBS-based regulatory framework. The description of the beta version of the PBS tool can be found in a Chalmers research report, see the publication list.

Additionally, some investigations on an alternative approach for implementing PBS in the regulatory framework, used in Canada, was conducted. In this approach PBS is used as an underlying basis for developing prescriptive regulations in form of “vehicle-

envelopes" which defines the general vehicle layout. The outcome of this study is published as a thesis report, see the publication list.

To summarize, the project has contributed to development and introduction of energy efficient HCT vehicles. The created knowledge can be used by vehicle manufacturers and transport companies to develop and select safer vehicles that also meet the societal challenges in energy and climate change and satisfy the transport demands. The project outcome can be used by the authorities for regulating HCT vehicles. The project has increased the Swedish competence within the scope of performance and regulation of HCT vehicles and reinforced collaboration between the vehicle industry, authorities, universities and research institutes. Furthermore, the project results have been disseminated in the international scientific community, in form of publications and presentations.

# 7. Dissemination and publications

Here is a list of project publications, in order of publication year:

- Kharrazi, S., Aurell, J., Kati, M. S., Jacobson, B., Fröjd, N. and Asp, T., "Towards performance based standards in Sweden". Proceedings of the 13th International Heavy Vehicle Transport Technology Symposium, San Luis, Argentina, 2014.
- Kharrazi, S., Karlsson, R., Sandin, J. and Aurell, J., "Performance based standards for high capacity transports in Sweden – FIFFI project 2013-03881 – Report I – Review of existing regulations and literature". VTI, report 859A, 2015.
- Tomar, A. S., "Steady state rollover threshold for high capacity transport vehicles – a novel calculation method". Chalmers Master thesis report, 2015.
- Kharrazi, S., "Performance of high capacity vehicles – winter versus summer". In proceedings of the International Symposium on Heavy Vehicle Transport Technology (HVTT14), Rotorua, New Zealand, 2016.
- Bruzelius, F., Kharrazi, S. and Pettersson, E., "Model and road surface sensitivity of longitudinal Performance based standards". In proceedings of the International Symposium on Heavy Vehicle Transport Technology (HVTT14), Rotorua, New Zealand, 2016.
- Jacobson, B., Sundström, P., Kharrazi, S., Fröjd, N. and Islam, M., "An open assessment tool for performance based standards of long combination vehicles". Chalmers research report, 2017.
- Kashampur, K., "Assessment tool for performance of high capacity combination vehicles including envelopes for A-double vehicles". Chalmers Master thesis report, 2017.
- Kharrazi, S., Bruzelius, F., Sandberg, U., Performance based standards for high capacity transports in Sweden – FIFFI project 2013-03881 – Final report. VTI, report 948A, 2017 (under review for publications).
- Bruzelius, F., Kharrazi, S., "Low speed performance based standards for Nordic countries". To be submitted for publication
- Islam, M., Fröjd, N., Kharrazi, S. and Jacobson, B., "How well a single-track linear model captures the lateral dynamics of long combination vehicles". To be submitted for publication.

In addition to the published papers, the project results have been presented in the following conferences and seminars:

- HCT annual conference, Gothenburg, Sweden, 2014.
- 13th International Heavy Vehicle Transport Technology Symposium, San Luis, Argentina, 2014.
- HCT annual conference, Örebro, Sweden, 2015.
- 14th International Symposium on Heavy Vehicle Transport Technology, Rotorua, New Zealand, 2016.
- ITF workshop on modal shift, Cambridge, UK, 2016.
- Transportforum, Linköping, Sweden, 2017.
- HCT annual conference, Gothenburg, Sweden, 2017.
- Swedish HCT program steering group meetings

# 8. Conclusions and future research

A candidate set of performance measures have been investigated with respect to the Swedish conditions; correlation between HCT vehicles performance during winter and summer with respect to these measures have been studied, using simulations and experiments on test track. Furthermore, different assessment procedures and required model complexity for evaluation of HCT vehicles performance have been studied and proposals have been provided for a regulatory framework. The end results of the project are gathered in the VTI report 948A with the title: "Performance based standards for high capacity transports in Sweden – FIFFI project 2013-03881 – Final report". The report is under review for publication and will be published by the end of 2017. Additionally, during the project, the obtained results have been published in various reports and articles, a list of which is provided in the publication section.
There are plans for the continuation of the project and all project partners are interested in a continued collaboration. The focus in the planned continuation will be on developing standard tire models for assessment of HCT vehicles in a PBS scheme, completing the PBS tool and further development of the proposed assessment procedure in the PBS project.

# 9. Participating parties and contact persons

- The Swedish national road and transport research institute(coordinator), Sogol Kharrazi
- Chalmers University of Technology, Bengt Jacobson
- Volvo Groups Truck Technology, Magnus Olbäck
- Scania, Jolle Ijkema
- Parator Industri AB, Per Olsson
- Trafikverket, Tomas Asp
- Transportstyrelsen, Anders Gunneriusson