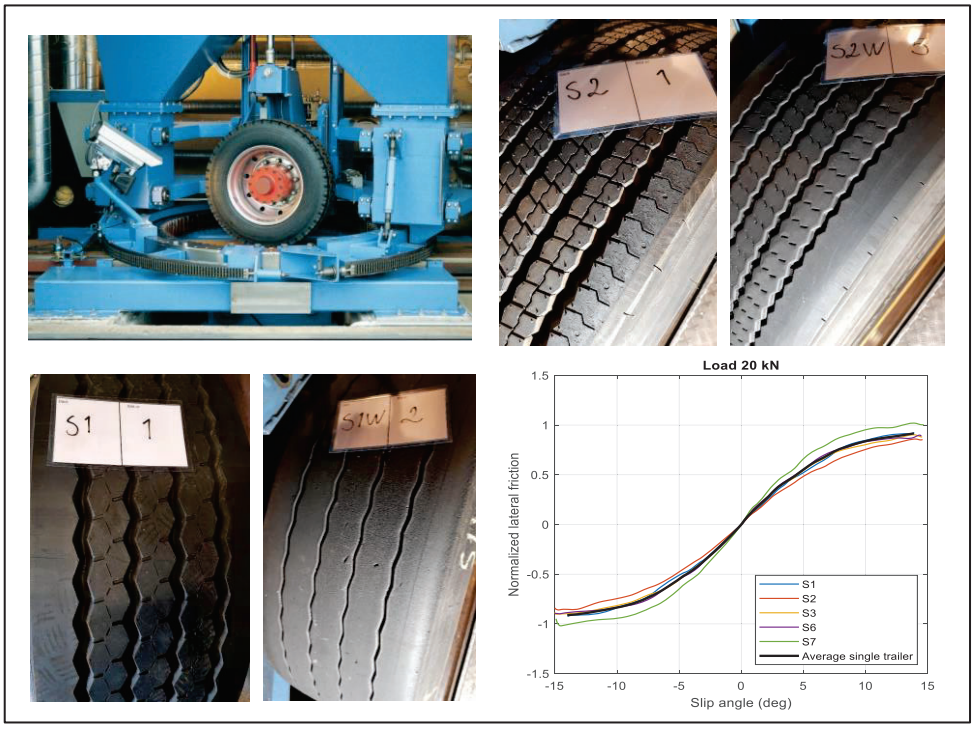
Performance Based Standards II

Public report



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FFI Fordonsstrategisk Forskning och Innovation
VINNOVA Energimyndigheten TRAFIKVERKET
FKG VOLVO SCANIA VOLVO

Content

1 Summary

High Capacity Transport (HCT) is part of Sweden's attempts towards a more efficient transport system. HCT vehicles are heavier and/or longer than conventional heavy vehicles and can carry more load per vehicle, resulting in less fuel consumption and emissions. In Sweden the legal length and weight limits for heavy vehicles are 25.25 m and 64 t. Also, from April 2018, heavier vehicles up to 74 t have been allowed on parts of the road network with a new bearing capacity named BK4. Introduction of vehicles longer than 25.25m is currently under consideration. In the neighboring country, Finland, the weight limit for heavy vehicles was increased to 76 t in 2013, and longer HCT vehicles up to 34.5 m are allowed on most of the road network since 2019.

After allowing HCT vehicles in Sweden, regulations concerning heavy vehicles access to road network have been modified and a PBS based regulation for 74 t vehicles have been introduced. PBS stands for performance based standards, under which the required performance from the vehicles is regulated, instead of limiting their length or weight. The purpose of the PBS II project has been to contribute to further development of the PBS scheme in Sweden and to support its implementation. One important aspect which required further investigation was the effect of tire characteristics on the performance of the HCT vehicles. Also, the assessment procedure of the HCT vehicles and a corresponding tool for it, demanded further developments. These issues have been addressed in the PBS II project, resulting in standard tire models for assessment of HCT vehicles, as well as an improved open access PBS tool. The project has been coordinated by VTI, Swedish national road and transport research institute. Other parties in the project are Chalmers University of Technology, Volvo Group Trucks Technology, Scania, Trafikverket, Transportstyrelsen, Parator industry AB, Nokian Heavy Tyres Ltd (Finland) and University of Oulu (Finland). PBS II project started in autumn 2018 and was concluded at the end of 2021.

2 Sammanfattning på Svenska

High Capacity Transport (HCT) är en del av Sveriges strävan mot ett effektivare transportsystem. HCT-fordon är tyngre och/eller längre än konventionella tunga fordon och kan bära mer last per fordon vilket resulterar i mindre bränsleförbrukning och utsläpp. I Sverige är de lagliga längd- och viktgränserna för tunga fordon 25,25 m och 64 ton. Från 2018 har även tyngre fordon upp till 74 t tillåtits på delar av vägnätet med en ny bärighet som heter BK4. Introduktion av fordon längre än 25,25 m övervägs i nuläget. I grannlandet Finland höjdes viktgränsen för tunga fordon till 76 ton år 2013 och längre fordon på upp till 34,5 m är tillåtna på större delen av vägnätet sedan 2019.

Efter införandet av HCT-fordon i Sverige har reglerna för tunga fordons tillträde till vägnätet ändrats och en PBS-baserad föreskrift för 74 tons fordon har införts. PBS står för "performance based standards" eller prestandabaserade kriterier på svenska. Vid ett PBS-system specificeras kriterier för prestandanivåer som ett fordon måste uppfylla istället för att sätta gränser för fordonets längd eller vikt. Syftet med PBS II projektet har varit att bidra till vidareutvecklingen av PBS-systemet i Sverige och att stödja dess genomförande. En viktig aspekt som krävde ytterligare undersökning var effekten av däckens egenskaper på HCT-fordons prestanda. Dessutom fanns det behov av att vidareutveckla metoder och verktyg för bedömning av HCT-fordon. Dessa frågor har studerats i PBS II-projektet och har resulterat i standarddäcksmodeller för bedömning av HCT-fordon, samt ett fritt tillgängligt och förbättrat PBS-verktyg. Projektet har koordinerats av VTI, Statens väg- och transportforskningsinstitut. Andra parter i projektet är Chalmers tekniska högskola, Volvo Group Trucks Technology, Scania, Transportstyrelsen, Trafikverket, Parator Industri AB, Nokian Heavy Tyres Ltd (Finland) och Oulu universitet (Finland). PBS II-projektet startade hösten 2018 och avslutades i slutet av 2021.

3 Background

The transport sector is facing a major challenge to reduce energy consumption and limit its environmental impact. This makes the High Capacity Transport (HCT) vehicles an attractive alternative to the conventional heavy vehicle combinations on the road; an alternative which also results in significant economic benefits. HCT vehicles are heavy vehicle combinations with higher load capacity (longer and/or heavier) than the existing vehicles on the roads. The existing legislation in Sweden, allows heavy vehicles with maximum length of 25.25 m and maximum weight of 64 t. However, from April 2018, heavier vehicles up to 74 t have been allowed on a designated part of the road network, classified as a new road category with higher bearing capacity, labeled BK4. In the neighboring country, Finland, the weight limit for heavy vehicles was increased to 76 t in 2013, and longer HCT vehicles up to 34.5 m are allowed on most of the road network since 2019. Different studies and trials with HCT vehicles have shown their potential in considerable fuel saving and CO_2 reduction. According to the Sweden HCT road map from 2019, HCT vehicles reduce the energy consumption per ton-km by about 10%. Larger savings have also been reported, for instance in the ETT projects.

To gain more knowledge about HCT vehicles and their effects on traffic safety, infrastructure and environment, the Swedish government has been undertaking a large research program focused on HCT vehicles. One of the work packages in the HCT program is Performance Based Standards (PBS), which 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 or infrastructure. In the first national PBS project, financed by Vinnova with registration number 2013-03881, extensive research was performed on safety aspects of HCT vehicles resulting in a proposal of a PBS scheme.

The outcomes of the first PBS project highlighted the importance of tire dynamics on assessment of heavy vehicles. The necessity of further studies on effect of tire characteristics on performance of HCT vehicles, as well as the need for further development of a PBS tool, prompted a second project in this area. Thus, PBS II project was initiated in autumn 2018 with parties from Swedish and Finnish stakeholders and was concluded three years later at the end of 2021.

4 Purpose, research questions and method

One of the main research questions addressed in the PBS II project is effect of tire dynamics on the performance of HCT vehicles and how to handle it in a PBS scheme. Due to the existing variety of tires and the diversity of road surface conditions, choosing one tire for assessing HCT vehicles is not a trivial task. To propose standard tire model(s), different tire types and their characteristics should be studied. Therefore, the existing range of truck tires in the Nordic market were explored and a group of truck tires were selected for measurements and further analysis.

4.1 Tire measurements

The purpose of tire measurements was to investigate tire characteristics, such as cornering coefficient, peak friction, and relaxation length. These tire characteristics were used for developing and proposing representative standard tires to be used in the Swedish PBS scheme. The measurements were carried out with new and worn tires on dry asphalt and smooth ice at VTI tire test facility in Linköping, see Figure 1. Some extra measurements on wet asphalt were also performed.

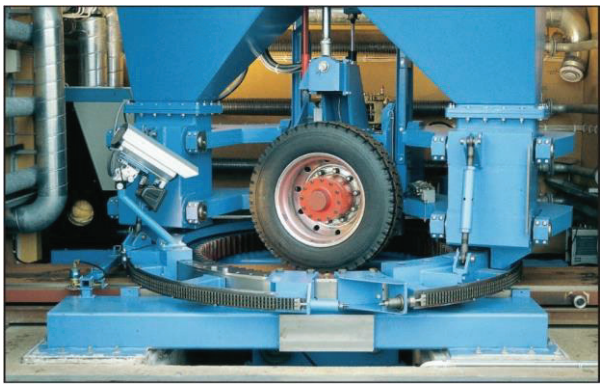

Figure 1. VTI tire test facility

Additionally, a few of the selected tires were measured on snow on a test track in Finland using a test trailer developed during the project, by University of Oulu, see Figure 2. The performance of the test trailer was assessed by performing measurements on asphalt and comparing it with measurements of the same tire at VTI tire test facility.

Eleven different tires were selected for the study. One new sample of each tire and different worn specimens of seven tires were obtained. In total 21 tire specimens were measured. The tread depths for the new specimens typically were within 13-19 mm, and in the range of 2-10 mm for the worn ones. Before the measurements, the new test tires were simultaneously driven in for 300 km, mounted on a fully loaded B-double combination with axles suitable for all the test tires.

The tires are listed in Table 1 and belong to three main categories: wide single steer/trailer tires (denoted by S), twin drive tires (denoted by D), and twin trailer tires (denoted by T). Based on the common axle loads for each category, the nominal loads were chosen as 40 kN for S tires, 22.5 kN for D tires, and 20 kN for T tires. In addition to the nominal load, the tires were measured at 50% and 150% of the nominal load.

The tires can be further subdivided into winter, multi-use, and fuel type. These different tire types can briefly be described as:

- Winter tires: Typically, these tires have small block pattern and/or dense deep siping. They also have special winter tread compound which can operate in low temperatures.
- Multi-use tires: Typically, these tires are designed for both regional and long distance driving and are for all-season use. They have bigger tread blocks and less siping than winter tires and have good mileage properties.
- Fuel tires: Typically, these tires are designed for long haul driving. They have low tread depth and normally no siping. They have special casing and tread compound designed to get low rolling resistance.

Figure 2. Tire testing trailer of University of Oulu

Table 1 – Tested tires

No	Code name	Dimension	Rim size (in)	Tire type	Condition	Tread depth (mm)
1	S1	385/65	22.5	Multi-use	new	17
2	S1W				worn	10
3	S1W2				worn	6
4	S1W3				worn	3
5	S2	385/65	22.5	Winter	new	16
6	S2W				worn	8
7	S2W2				worn	5.5
8	S3	385/65	22.5	Multi-use	new	15
9	S3W				worn	7
10	S4	385/65	22.5	Fuel	new	13
11	S5	385/55	22.5	Winter	new	15
12	S6	385/65	22.5	Winter	new	16
13	S7	385/65	22.5	Multi-use	new	12.5
14	D1	315/70	22.5	Multi-use	new	18
15	D1W				worn	3.5
16	D2	315/70	22.5	Winter	new	19
17	D2W				worn	6
18	T1	265/70	19.5	Multi-use	new	13.5
19	T1W				worn	3
20	T2	265/70	19.5	Winter	new	14
21	T2W				worn	2

4.2 Tire modeling and simulations

Validated vehicle models, developed in the first PBS project, were used to run simulations, and compare different tire model complexities and their effects on the HCT vehicles performance. PBS measures such as offtracking, rearward amplification and yaw damping were used for comparisons. The obtained tire force-slip curves from measurements were used to parameterize the models and identify representative tire characteristics on high and low friction road surfaces.

4.3 Experiments with an Adouble

Using several specimens of one of the tires, namely S1, the effect of tire characteristics on the performance of an HCT vehicle was studied using new and worn tires. The tests were performed by Scania on an A-double (tractor-semitrailer-dolly-semitrailer) whose dolly and last semitrailer were equipped with S1 tires, see Figure 3.

Figure 3. The Adouble vehicle tested by Scania

Testing was performed with three tire configurations:

- New tires on both the dolly and the last semitrailer
- Worn tires on both the dolly and the last semitrailer
- Worn tires on the dolly with new tires on the semitrailer

The performed tests were a series of single sine inputs with varying amplitude and frequency at speed of 80 km/h. Vehicle speed was maintained with cruise control and a steering robot was used for the steer input. A series of random tests were performed as well, where the driver manually steered the vehicle with a sinusoidal steering input with continuously increasing frequency. The vehicle lateral performance with the three different tire configurations were analyzed and compared using metrics such as offtracking, rearward amplification and peak lateral acceleration. The gathered test data was also used for validating simulation results with the developed tire models.

4.4 PBS tool

In a PBS-scheme, there is a need for a PBS tool to be used by the authorities for assessing the HCT vehicles performance, or by the haulers and manufacturers for developing and selecting safe and efficient HCT vehicles. Development of such a tool initiated in the first PBS project and a beta-version of an open access PBS tool, named OpenPBS, was created. Also, during that period Transportstyrelsen developed a web-based tool for assessment of the 74 t HCT vehicles, called lastbilskalkylator.

In the PBS II project, the open access PBS tool was further developed, resulting in a demonstrator for assessment of HCT vehicles. The required vehicle parameter values for the demonstrator were limited to what is available from the vehicle registry so it can be used by Transportstyrelsen. When needed, nominal vehicle parameter values were suggested.

5 Objective

The project's objective was to continue with the development of a performance based regulation of HCT vehicles and their access to the road network in Sweden. The project goals, as formulated in the application to Vinnova, were:

- Development of standard tires for assessment of HCT vehicles performance
- Further development of performance measures suitable for Sweden, and corresponding assessment procedures
- Supporting Transportstyrelsen in development of the PBS web-tool
- Exchanging knowledge and expertise within the area of HCT vehicles with international actors from Finland and other countries.

All the project objectives have been addressed throughout the project.

6 Results and deliverables

The project results are:

- Standard tire models for assessment of HCT vehicles performance
- Further development of an open access PBS tool, presented as a demonstrator for computational assessment and evaluation of HCT vehicles
- Further development of PBS regulatory framework for HCT vehicles in Sweden
- ISO standards and publications

The PBS II project has followed the planned activities well and the achieved results match the anticipated ones listed in the application to Vinnova. The project has been focused on development of standard tire models and improvement of a PBS tool, which together have contributed to further development of the PBS regulatory framework in Sweden.

After analyzing tire measurement data and comparison of tire models with different complexity, a simplified version of magic formula tire is proposed and parameterized to create standard tire models. The focus has been on a standard model for wide single steer/trailer tires, but suggestions for twin trailer tires and twin drive tires are also provided. The models are parameterized for both high and low friction road surfaces. Additionally, methods on how to model effects of the tire wear and thread depth are provided. More detailed results on the tire modeling can be found in a VTI report (Kharrazi & Hjort 2022) which is under preparation and will be publicly accessible via VTI website.

OpenPBS is an open access PBS tool implemented in Modelica, development of which started in the first PBS project and continued in the second project. During PBS II project, the assessment models/algorithms in the OpenPBS are improved and updated according to the determined required complexity in the PBS projects. Steerable axles are modelled and added to the tool. The input data and interface are updated to be compatible with the available data in the vehicle registry, and the user is only asked to provide values which are easy to obtain, such as axle loads and load height. The improved OpenPBS has been used to further evaluate the lastbilskalkylator and suggestions for its improvements are provided to Transportstyrelsen. The OpenPBS can be exploited by Transportstyrelsen to develop a second version of lastbilskalkylator that can be used for assessment of both longer and heavier vehicles.

An ISO standard has been prepared and proposed based on the outcomes of the project on methods for estimation of steady state rollover threshold of heavy vehicles. Another ISO standard on tire models is under preparation using the gathered tire data and the developed models in the project. The project results have been and will be published as articles and thesis work reports and presented at conferences and at the Swedish HCT program steering group meetings.

7 Dissemination and publications

The project results have been dissipated as reports, articles, presentations, standards, and an open access PBS tool. More details are provided in the following subsections.

7.1 Dissemination of knowledge and results

The project has enhanced the Swedish competence within the scope of performance and regulation of HCT vehicles and tire modeling. It has also increased the exchange of knowledge and expertise in this field with Finland and other countries. The project will contribute to development and implementation of energy efficient HCT vehicles. The created knowledge in the project can be used by vehicle manufacturers and transport companies to develop and select safer and more efficient vehicles which comply with the regulations. The project outcomes can also be used by the authorities in regulation of HCT vehicles access to the road network in Sweden.

The outcomes of the project have been used to develop and propose two new ISO standards, one on performance assessment of heavy vehicles, and another one on tire modeling. Members of the PBS II project have been leading the standardization projects within the ISO working group on vehicle dynamics of heavy commercial vehicles and buses, which is part of subcommittee 33 on vehicle dynamics and chassis components (ISO/TC 22/SC 33/WG 6).

Here are the titles of the two proposed ISO standards, which are at different stages of development:

- Heavy commercial vehicles and buses – Calculation method for steady state rollover threshold. *Draft International Standard (DIS) is submitted for final approval*.
- Heavy commercial vehicles and buses – Vehicle dynamics simulation and validation – Tyre model for lateral estimation of heavy vehicle combinations operated at dry paved road surface well below peak friction utilization, *working draft*.

Table 2 – An overview of dissemination of knowledge and results

How has/will the project result be used and disseminated	Mark with X	Comments
Increase knowledge in the field	x	Increased knowledge in tire modeling and PBS for HCT
Passed on to other advanced technical development projects	x	The tire data and tire modeling methods, as well as the OpenPBS tool can be used in projects within this area.
Passed on to product development projects	x	The OpenPBS tool can be used by Transportstyrelsen for development of next version of lastbilskalkylator.
Introduced to the market	x	The tire models and OpenPBS tool can be used by vehicle manufacturers and transport companies to develop and select safer and more efficient vehicles.
Used in investigations/ regulations/ permits/ political decisions	x	Project outcomes can be used by the authorities in regulation of HCT vehicles access to the road network. Also, ISO standards have been proposed based on the outcomes of the project

7.2 Publications

Project results have been disseminated in the international scientific community, in form of publications, presentations and standards. A list of the project publications is provided below. Additional articles are planned to be written and published from the project results.

V. Santahuhta, 2019, “Roll dynamics and tyre relaxation in heavy combination vehicle models for transient lateral manoeuvres”. Master thesis report, Chalmers.
https://hdl.handle.net/20.500.12380/300379

M. Karisaari, 2020, “Modelling and assessment of performance based standards for high capacity vehicles”. Master thesis report, Chalmers.
https://hdl.handle.net/20.500.12380/301630

L. Reddy, 2021, “Modelling of steered and lifted axles on long combination vehicles for performance based measures”. Master thesis report, Chalmers.
https://hdl.handle.net/20.500.12380/304265

M. Hjort, S. Kharrazi, N. Fröjd, T. Siltanen, 2021, “Tyre modelling for high capacity vehicle simulations”, In proceedings of the 16th Heavy Vehicle Transport and Technology Symposium (HVTT16). Trinity College Dublin (hvttforum.org)

S. Kharrazi, M. Hjort, 2022, “Performance Based Standards II – FFI project 2018-01934”, VTI report, under preparation for publication.

8 Conclusions and future research

PBS II project was planned and commenced with the objective to contribute to further development of a PBS scheme for HCT vehicles in Sweden. This objective has been achieved via development of standard tire models for performance assessment of HCT vehicles, as well as enhancement of an open-access assessment tool in Modelica, called OpenPBS.

A selection of representative truck tires from the Nordic market were selected and measured. Using the gathered tire data, standard tire models to be used in the Swedish PBS scheme have been proposed. OpenPBS, the open access PBS tool, has been further developed with improved assessment models/algorithms, inclusion of steerable axles, and input data which are compatible with the vehicle registry. The project results have been published in reports and articles and presented at conferences. Further, ISO standards have been developed and proposed based on the outcomes of the project. The detailed result of the project is under publication in a VTI report: “S. Kharrazi, M. Hjort, 2022, Performance Based Standards II – FFI project 2018-01934”.

One recommendation for future research is to expand the standard tire modeling. In the PBS II project, the focus has been on a standard model for wide single steer/trailer tires. Suggestions for twin trailer tires and twin drive tires have been proposed which can be scrutinized by more data and measurements. Also, data on overturning moments of truck tires and their dependency on load and slip angle is very sparse; in PBS II project, efforts for filling this gap of knowledge started, which should be continued. Another remining future task is to assist Transportstyrelsen in creating an improved version of lastbilskalkylator based on the OpenPBS tool developed in the PBS II project.

9 Participating parties and contact persons

PBS II project includes partners from Swedish and Finnish stakeholders. Here is a list of the partners:

- VTI, Sogol Kharrazi (coordinator) & Mattias Hjort
- Chalmers University of Technology, Bengt Jacobson
- Volvo Groups Truck Technology, Niklas Fröjd & Magnus Olbäck
- Scania, Jolle Ijkema
- Trafikverket, Thomas Asp
- Transportstyrelsen, Omar Bagdadi
- Parator Industri AB, Per Olsson
- Nokian Heavy Tyres Ltd (Finland), Teppo Siltanen
- University of Oulu (Finland), Miro-Tommi Tuutijärvi