PERFORMANCE OF HIGH CAPACITY VEHICLES WINTER VERSUS SUMMER

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Abstract
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 Vehicles (HCVs) an attractive solution. In order to introduce HCVs in Sweden, the existing regulations should be modified; one approach is to use performance based standards (PBS) as in e.g. Australia and Canada. However, it is very important that the winter road conditions in Sweden is considered and a PBS system suitable for Swedish condition is developed. In this paper performance of a selection of HCVs are compared for both summer and winter condition, which shows a strong correlation between the two.

Keywords: High Capacity Vehicles, Performance Based Standards, Low Friction, Rearward Amplification, Offtracking, Yaw Damping, Load Transfer Ratio

1. Introduction

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 Vehicles (HCVs) an attractive alternative to the conventional heavy vehicle combinations on the road; an alternative which is also expected to result in significant economic benefits. HCVs are heavy vehicle combinations that are longer and/or heavier than the existing vehicles on the roads. With HCVs, 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 25.25 metre and maximum weight of 64 ton (increased from 60 ton in June 2015). However, dispensations of longer and heavier HCVs for trial periods have been granted which have shown considerable CO_2-reduction, fuel saving and improved transport economy (Cider & Ranäng 2013, Adell et al. 2014). In order to introduce HCVs in Sweden, the existing regulations should be modified and a proper way of regulating HCVs and their access to the road network should be developed to ensure that a certified HCV 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, standards would specify the performance required from vehicle, rather than mandating how this level of performance should be achieved and putting limits on the vehicle length or weight. There are different approaches for implementing PBS in a regulatory framework, such as using PBS as an underlying basis for developing prescriptive regulations like the Canadian approach where "vehicle-envelopes", defining the general vehicle layout, were developed using PBS (Woodrooffe et al. 2010). Another example is the Australian approach in which PBS is used to determine access requirement for different parts of the road network and is complementary to the general prescriptive regulations (NTC 2008). 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.

With a PBS approach for regulation of heavy vehicles on roads, development of cost effective HCVs without negative effects on traffic safety, infrastructure and environment will be possible. Furthermore, the inherent flexibility in the PBS approach allows industry to develop innovative vehicles optimized for a specific application. Therefore, 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 performance based regulation of HCVs and their access to the road network (Kharrazi et al. 2014).

An important aspect of the Swedish PBS project is to formulate a set of performance based standards which takes into account the winter road conditions in Sweden. Therefore a selection of performance measures are under investigation with respect to both high and low friction surfaces, to check weather a correlation between performance of HCVs in winter and summer exist or not. In this paper the result of this study with focus on lateral dynamics is presented.

2. Performance Measures

In this study, the most commonly used performance measures that characterize different aspects of the lateral performance of heavy vehicle combinations, namely rearward amplification (RWA), offtracking and yaw damping are considered (Aurell & Winkler 1995). Furthermore load transfer ratio (LTR) which represents risk of rollover is included. Description of each of these performance measures is provided in the following paragraphs (Kharrazi et al. 2015).

Rearward amplification: In a sudden manoeuvre at high speeds, the lateral motion of the hauling unit of a heavy vehicle combination is amplified increasingly by each successive unit; this phenomenon is called rearward amplification and is a matter of concern for vehicle combinations with more than one articulation point. Rearward amplification is defined as the ratio of the peak value of a motion variable of interest for the rearmost unit to that of the hauling unit, see Figure 1. It is usually given in terms of lateral acceleration or yaw rate, both of which are considered in this study. Rearward amplification of yaw rate and lateral acceleration indicates the increased risk for a swing out or rollover of the last unit, respectively, compared to what the driver is experiencing in the hauling unit. Rearward amplification may be determined based on the vehicle's response gain in the frequency domain or in a specific transient manoeuvre; here a single lane change manoeuvre is used.

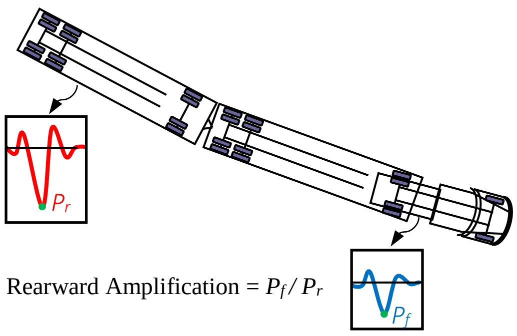

Figure 1 – Illustration of RWA, *P* denotes peak value of the motion variable of interest

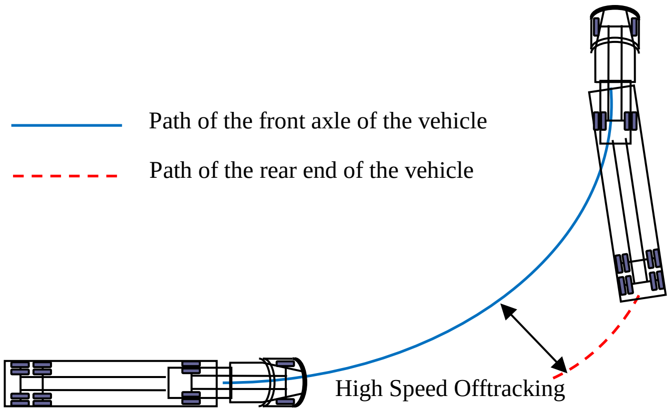

Figure 2 – Illustration of high-speed offtracking

Offtracking: During a sudden manoeuvre at high speeds, the rear end of the heavy vehicle track outboard the prescribed path. The maximum distance between the paths of the rearmost axle of the vehicle and the front axle in a dynamic manoeuvre is called high-speed transient offtracking and should be limited, see Figure 2. In this study path of the rear end of the last unit is considered instead of the rearmost axle, for the sake of fair comparison, due to different positioning of the axles in different combinations. High-speed transient offtracking is an indicator of the potential intrusion into adjacent lanes or interference with the roadside objects.

Yaw damping: After performing a severe manoeuvre, the swinging or yaw oscillations of the towed units in heavy vehicle combinations decay with various rates. The yaw damping coefficient is a measure of how quickly these oscillations settle down and is defined as damping ratio of the least damped articulation joint of the heavy vehicle combination. Yaw damping ratio of an articulation joint is determined from the amplitudes of the articulation angle of subsequent oscillations. Low yaw damping coefficient result in prolonged swinging of the towed units and can lead to loss of control or collision with a vehicle in an adjacent lane or roadside object.

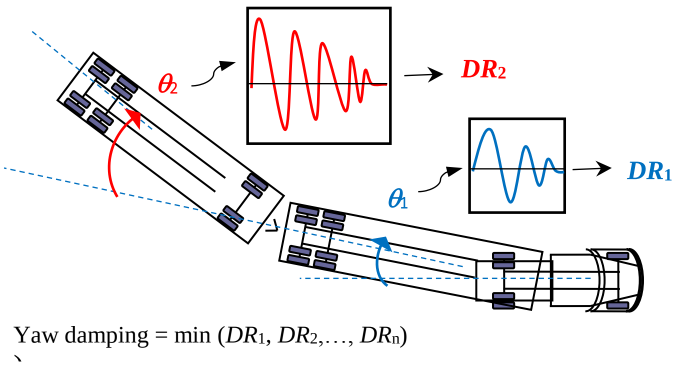

Figure 3 – Illustration of yaw damping, *DR* is damping ratio of the articulation joint

Load Transfer Ratio: It is a measure of the roll stability of a heavy vehicle and characterizes how close a vehicle gets to rolling over in a dynamic manoeuvre. It measures the fractional change in the load carried on the left and right side tyres, which indicates the proximity of a total lift off. This measure can be expressed as an average value, as in Equation 1, for all axles. LTR has a value of 0 when the vehicle is at rest and will rise to a value of 1 when all of the vehicle/axle load transfers to one side.

$$LTR = \frac{\sum|F_L - F_R|}{\sum(F_L + F_R)} \qquad (1)$$

3. Vehicle Combinations

A selection of heavy vehicle combinations, representing current fleet in Sweden and prospective HCVs are modelled, shown in Table 1. The performance of these vehicles during a lane change manoeuvre both in summer and winter are simulated and compared.

Table 1 – List of modelled heavy vehicle combinations

	Heavy Vehicle Combination	Axle Configuration*	Size
1	Tractor-Semitrailer	TR4x2-ST3	40t, 16.5m
2	Tractor-Link trailer-Semitrailer	TR6x4-LT3-ST3	74t, 25.4m
3	Tractor-Semitrailer-Centre Axle Trailer	TR4x2-ST3-CT2	60t, 25.1m
4	Tractor-Semitrailer-Dolly-Semitrailer	TR6x4-ST3-DY2-ST3	94t, 31.0m
5	Tractor-Link Trailer-Link Trailer-Semitrailer	TR5x4-LT2-LT2-ST3	90t, 33.7m
6	Truck-Centre Axle Trailer	TK6x2-CT2	40t, 18.8m
7	Truck-Dolly-Semitrailer	TK6x2-DY2-ST3	60t, 24.1m
8	Truck-Centre Axle Trailer-Centre Axle Trailer	TK6x2-CT2-CT2	60t, 27.6m
9	Truck-Dolly-Link Trailer-Semitrailer	TK6x4-DY2-LT2-ST3	90t, 32.4m

* **TR**=Tractor, **TK**=Truck, **ST**=Semitrailer, **CT**=Centre axle trailer, **LT**=Link trailer, **FT**=Full trailer, **DY**= Dolly
The number following each unit name indicates number of axles, for the powered unit the common notation of number of wheels followed by number of driven wheels is used instead.

4. Modelling and Validation

The Volvo vehicle model library, with some modifications, was used to model the selected vehicle combinations. The tool used for modelling is Matlab-Simulink. An important factor for comparing the performance of the vehicles on high and low friction surfaces is the tire modelling. For this purpose, tire data measured at VTI tire testing facility and data from the VERTEC European project (Dodd 2006) were used. The simulation results were compared with test data gathered in summer and winter for several vehicle combinations to validate the models. The results show an acceptable level of accuracy of the models. Some sample results are shown in Figure 4 and Figure 5. Some tuning of the tire cornering stiffness and friction level was allowed to match the test data.

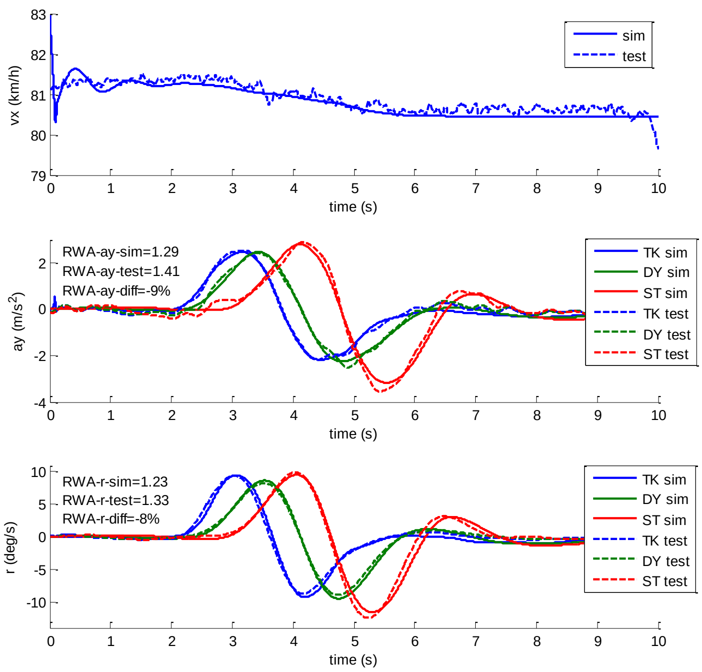

Figure 4 – TK-DY-ST combination in a lane change manoeuvre on dry asphalt simulation vs. test data

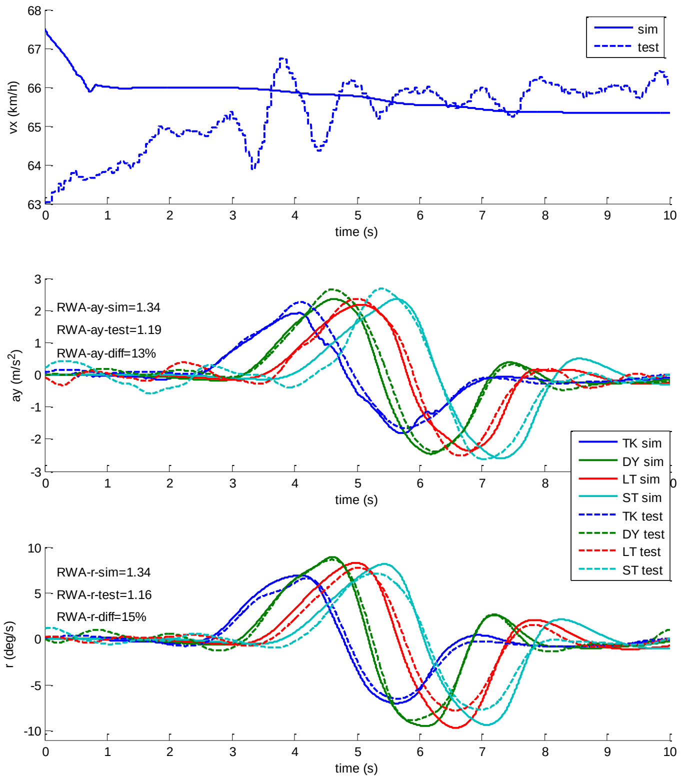

Figure 5 – TK-DY-LT-ST combination in a lane change manoeuvre on snow simulation vs. test data

It should be noted that for the winter condition, the cornering stiffness of tires that resulted in a good match with the test data was higher than the tire data gathered for the VERTEC project; this was not unexpected considering the extreme variety of winter conditions. Thus in the final simulation and comparison of the vehicle combinations listed in Table 1, a cornering stiffness value between the two was used.

5. Results

All the vehicle combinations selected for this study are simulated in three manoeuvres: an open loop single lane change (SLC) on dry asphalt, as well as a closed loop SLC at the speed of 70km/h. The speed is chosen so that all vehicle combinations can undergo the manoeuvres without complete loss of control. The third manoeuvre is an open loop SLC on snow at speed of 60km/h.

For the closed loop single lane change manoeuvre, a simple PID driver model for following the desired path, defined according to the ISO standard (ISO 2002), is used. The purpose is to check the correlation between the vehicle performance during a simulated open loop manoeuvre and a simulated closed loop manoeuvre. For the open loop SLC, a sinusoidal steer input with frequency of 0.4Hz is used; the amplitude is adjusted for each vehicle to result in a 3m lateral displacement of the front axle, so that the vehicles perform similar lane changes. For the closed loop manoeuvre, a lateral acceleration of $2 m/s^2$ at the front axle and a frequency of 0.33Hz is used to define the desired path. This results in a 3m lane change which is comparable with the open loop SLC. The achieved results are shown in Figure 6; it can be seen that the results of the open loop and closed loop manoeuvres are highly correlated for all the relevant performance measures. Care should be taken before generalizing this result, due to its dependency on the utilized driver model.

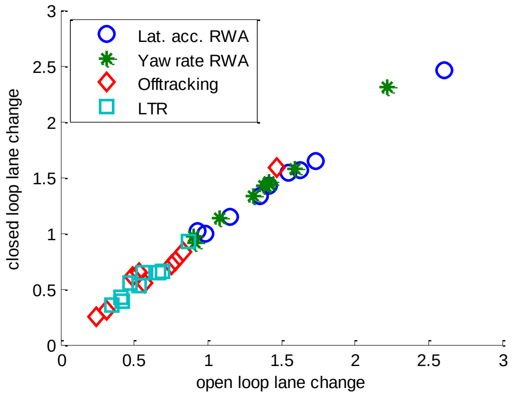

Figure 6 – Correlation between the performances of vehicles, closed loop vs. open loop

The open loop SLC manoeuvre on the snow is simulated in the same fashion as for the dry asphalt; however, the speed is reduced to 60km/h. Figure 7 depicts the correlation of the studied performance measures during winter and summer. Both rearward amplification of lateral acceleration and yaw rate in winter are highly correlated with the achieved values for summer. It can also be seen that the RWA values for winter and summer are comparable; however, poor performance on dray asphalt and large yaw rate RWA values in summer is linked with swing out and very large RWA values in winter. The correlation between winter and summer performance can be observed clearly for the offtracking as well. The difference is that the offtracking values are considerably larger for winter conditions compared to summer, the truck with two centre axle trailers, which has the worst performance in summer, reaches instability and swings out on snow. As expected, load transfer ratio is not an issue during winter, due to lower levels of lateral acceleration.

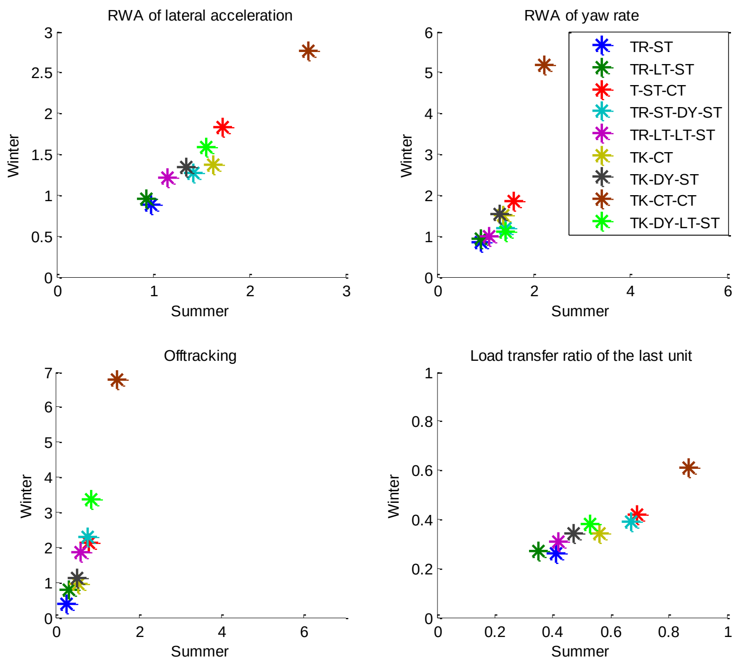

Figure 7 – Correlation between performance of the vehicles, winter vs. summer

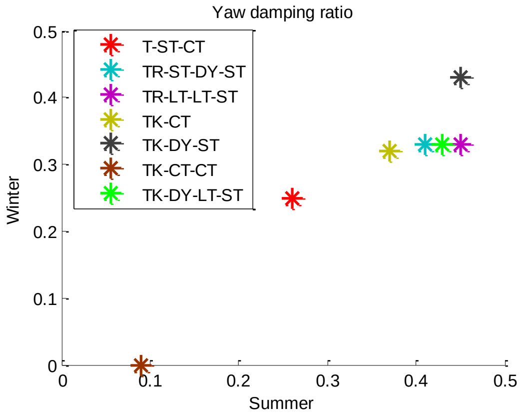

Figure 8 – Yaw damping ratio, winter vs. summer

The yaw damping ratio after the completion of the steering input for the lane change in the open loop manoeuvre is calculated for winter and summer and potted against each other in Figure 8. Tractor-semitrailer and tractor-link trailer-semitrailer combination are not included in the figure, since they are too damped in this manoeuvre and no oscillation can be observed to calculate yaw damping ratio. All the obtained values from the simulations are provided in Table 2 to Table 4.

Table 2 – Rearward amplification, winter vs. summer

	Lat. acc. RWA			Yaw rate RWA		
Heavy Vehicle Combination	**CL**	**OL**	**Snow**	**CL**	**OL**	**Snow**
Tractor-Semitrailer	1	0.98	0.88	0.91	0.91	0.86
Tractor-Link trailer-Semitrailer	1.02	0.93	0.95	0.97	0.9	0.94
Tractor-Semitrailer-Center Axle Trailer	1.65	1.73	1.83	1.57	1.59	1.86
Tractor-Semitrailer-Dolly-Semitrailer	1.43	1.42	1.27	1.44	1.42	1.2
Tractor-Link Trailer-Link Trailer-Semitrailer	1.15	1.15	1.21	1.13	1.08	1
Truck-Center Axle Trailer	1.56	1.63	1.37	1.42	1.38	1.51
Truck-Dolly-Semitrailer	1.33	1.35	1.34	1.33	1.31	1.53
Truck-Center Axle Trailer-Center Axle Trailer	2.46	2.61	2.76	2.31	2.22	5.18
Truck-Dolly-Link Trailer-Semitrailer	1.54	1.55	1.59	1.46	1.42	1.1

Table 3 – Offtracking and load transfer ratio, winter vs. summer

	Offtracking			LTR		
Heavy Vehicle Combination	**CL**	**OL**	**Snow**	**CL**	**OL**	**Snow**
Tractor-Semitrailer	0.25	0.24	0.39	0.43	0.41	0.26
Tractor-Link trailer-Semitrailer	0.31	0.31	0.78	0.35	0.35	0.27
Tractor-Semitrailer-Center Axle Trailer	0.75	0.78	2.14	0.66	0.69	0.42
Tractor-Semitrailer-Dolly-Semitrailer	0.71	0.75	2.28	0.65	0.67	0.39
Tractor-Link Trailer-Link Trailer-Semitrailer	0.55	0.57	1.86	0.39	0.42	0.31
Truck-Center Axle Trailer	0.65	0.53	0.96	0.64	0.56	0.34
Truck-Dolly-Semitrailer	0.61	0.49	1.11	0.55	0.47	0.34
Truck-Center Axle Trailer-Center Axle Trailer	1.59	1.47	6.79	0.92	0.87	0.61
Truck-Dolly-Link Trailer-Semitrailer	0.83	0.83	3.36	0.53	0.53	0.38

Table 4 – Yaw damping ratio, winter vs. summer

	YDR	
Heavy Vehicle Combination	**Asphalt**	**Snow**
Tractor-Semitrailer	-	-
Tractor-Link trailer-Semitrailer	-	-
Tractor-Semitrailer-Center Axle Trailer	0.26	0.25
Tractor-Semitrailer-Dolly-Semitrailer	0.41	0.33
Tractor-Link Trailer-Link Trailer-Semitrailer	0.45	0.33
Truck-Center Axle Trailer	0.37	0.32
Truck-Dolly-Semitrailer	0.45	0.43
Truck-Center Axle Trailer-Center Axle Trailer	0.09	0
Truck-Dolly-Link Trailer-Semitrailer	0.43	0.33

6. Conclusions

Lateral dynamics of nine heavy vehicle combinations, including both conventional vehicles and HCVs, during lane change manoeuvres in winter and summer are simulated and compared. Simulation results indicate a strong correlation between the studied performance measures for snow and dry asphalt. Among the studied measures, rearward amplification of lateral acceleration and load transfer ratio are the least critical ones for winter conditions, due to lower levels of lateral acceleration, thus additional criteria to address these measures for winter conditions seems unnecessary.

For rearward amplification of yaw rate and yaw damping ratio, although the values for winter and summer are not too different, the difference gets exaggerated for vehicle with poor performance which will result in swing out and instability in winter. Thus, considering the winter-summer correlation for these measures, a certain level of performance on summer, which also ensures stable performance in winter, should be advised. Offtracking is significantly larger for all the vehicles in winter compared with summer; however, there exist a strong correlation for this measure as well. Thus, similar to yaw rate rearward amplification and yaw damping ratio, the required level of performance in summer should be decided based on the existing correlation to ensure a limited offtracking during winter too.

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