Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria

High Capacity Transport vehicles vs. standard vehicles in Finland

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Abstract

Legislation of road vehicles was changed in Finland in 2013. The change allows the transport enterprises to get test licenses of specified time periods for vehicles, which exceed the limits of lengths and masses of the standard or normal vehicle combinations. The permanent legislation allows maximum gross mass of 76 t and length of 25.25 m for vehicles. The test vehicles (= HCT or High Capacity Transport vehicles) are mainly combinations with semi-trailers and/or trailers. So far (September 2017) number of these licences is more than 30. The Finnish Transport Agency (former Road Administration) ordered Vemosim Ltd to research the issue. The study includes driving resistance measurements of the HCT and standard vehicles. Based on these data fuel economy, carbon dioxide emissions and transportation costs are determined by simulation. Road wear impacts are determined, too. The interim conclusions are: the HCT vehicles are better than the normal vehicles in terms of fuel efficiency, CO_2 emissions and of road wear impacts, provided that the roads are built according to the extant road design norms.

Keywords: HCT (High Capacity Transport) vehicles; standard or normal vehicles; energy efficiency; CO_2 emissions; road wear impacts.

1. Introduction

The presentation describes the research project “Comparison of HCT (High Capacity Transport) vehicles with the standard or normal vehicles”, and its results.

The legislation concerning vehicle masses was changed in Finland in 2013. The GCM (Gross Combination Mass) was increased to 76 tons, if the combination has at least nine axles and at least 65 % of the trailer mass lies on axles with dual wheels. Test licences for specified time periods can be granted. These licenses allow the GCM more than 76 t and the combination length may be more than the legal 25.25 m. In order to avoid increase of the road wear impacts, the number of axles is increased so that the axle group masses are not increased. The HCT vehicles are mainly combinations with semi-trailers and/or trailers.

The Finnish Transport Agency (former Road Administration) engaged Vemosim Ltd to research the HCT and standard vehicles with the objectives: comparison of the HCT and normal vehicles from the point of view of fuel economy, CO_2 emissions, transport costs and road wear impacts.

The presentation covers three main issues and their results: measurements of drive resistances, simulation of fuel economy and CO_2 emissions, and road wear impacts. Transport costs, which are not included in this representation, will be included in the final research report.

2. Measurements of drive resistances

2.1. Drive resistance field measurements

The HCT vehicles differ from normal vehicles; their size is greater and they have more axles and wheels than the normal ones. Rolling resistance data for normal vehicles are available, but there is no rolling resistance data for the HCT vehicles. For this reason it was necessary to carry out drive resistance measurements.

When a vehicle is moving, its motion is resisted by drive resistance forces. These forces are the rolling resistance and the air resistance force. The potential grade resistance caused by the road gradient creates additional resistance force, too. The rolling resistance and air resistance data are needed in vehicle motion simulation.

Resistance values of the rolling and air resistances can be determined by the coast down method, in which the vehicle is allowed to “coast down” on a road section, whose gradient is constant over a long distance. Drive resistance measurements, including 182 separate test drives, were carried out with four HCT vehicles and three normal vehicles in 2016. Figure 1 indicates the study vehicles by comparison pairs.

When using the coast down method, a vehicle is accelerated up to an appropriate initial velocity, from which it is allowed to roll at neutral gear position while there is no traction force acting on it. The only forces acting on it are the rolling resistance and the air resistance as well as the potential road gradient resistance. The data of time, distance and speed was scanned second by second. The length of the measurement road section is 1410 m and gradient 0.083 percent.

2.2. Analysis of drive resistance field measurements

Analysis of the drive resistance measurements was most tedious and requiring part of the research project. The analysis includes: checking of the measurement results and their correctness, refining the raw measurement results, creating differential function for vehicle motion, and creating the model. In other words, solving the differential function in alternative ways, applying regression analysis to determine the model that best fits the measurement results. The results are the coefficient values of rolling resistance and of air resistance for each vehicle. Finally, the models of resistance coefficients concerning the test vehicles were developed.

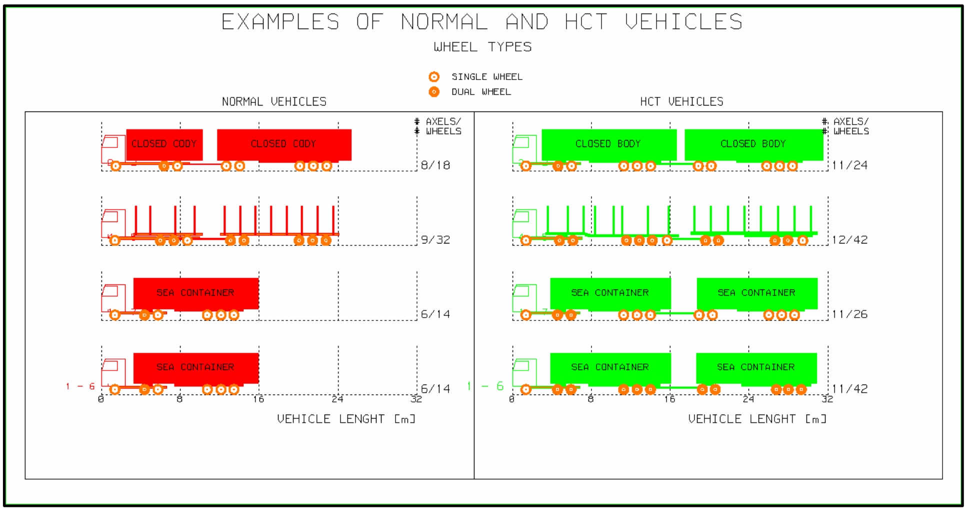

Fig. 1 Study vehicles (Normal and HCT vehicles) in drive resistance measurement

The drive analysis can be described by the following differential equation

$$m\ dv/dt = -m\ g\ (a_0 + q + a_1\ v) - a_2\ (v-w)^2 \tag{1}$$

where: m = vehicle mass [kg]

t = time [s]

v = velocity [m/s]

g = gravitational acceleration [m/s^2]

a_0 = rolling resistance base coefficient

a_1 = rolling resistance velocity coefficient [s/m]

a_2 = air resistance coefficient [kg/m]

q = road gradient

w = wind velocity [m/s]

In addition $a_2 = 0.5\ d_a\ c_d\ A_f$

where: d_a = air density [kg/m^3]

A_f = vehicle frontal area [m^2]

c_d = vehicle shape coefficient

By using the following assignments

$C_0 = g\ (a_0 + q)$

$C_1 = g\ a_1$

$C_2 = a_2/m$

$$D^2 = (4\,C_0\,C_2 - C_1^2)$$

and setting w = 0 the equation (1) can be converted to the form

$$dv/dt = -(C_0 + C_1\,v + C_2\,v^2) \qquad (2)$$

The solution of the differential equation (2) is

$$t = -2/D \arctan\,[(2\,C_2\,v_0 + C_1)/D] \qquad (3)$$

The inverse function of the equation (3) is

$$v = -C_1/C_2/2 + D/C_2/2 \tan\,[-D/2(t - t_0)] \qquad (4)$$

where: t_0 = time [s], when v_0 = initial velocity [m/s]

The equations (3) and (4) are fitted to the measurement data, and the best function coefficients by correlation coefficients and standard deviations are searched.

Based on equations of 3 and 4 the developed equation for rolling resistance coefficients of a vehicle is as follows:

$$y = A_0 + A_1\,(x_1 - p_0)^p + A_2\,x_2 + A_3\,x_1\,x_2 \qquad (5)$$

where: y = rolling resistance coefficient, x_1 = mass of vehicle [t] and x_2 = number of wheels

A_0, A_1, A_2, A_3, p and p_0 are coefficients and their values are obtained by regression analysis.

3. The application of the resistance coefficients in the vehicle motion simulation

The resistance coefficients are used in the vehicle motion simulation of different vehicle types with varying loading levels. The simulation results on the highway # 4 from Helsinki to Oulu in Finland are given here. The distance between Helsinki and Oulu is 600 km, and its rate of rise and fall is approximately the average of highways in Finland. Additionally, it was indicated that the simulations give same results for fuel consumption as the measurement for fuel consumption from the CAN bus of vehicle.

The vehicle motion simulation uses the following main input data:

- Technical characteristics of vehicles: fuel maps of the engines and other technical characteristics of the vehicles
- Technical characteristics of the road
- Driving techniques: selection of target speed and gear change strategy

The simulation gives fuel usage, driving time and several other quantities. CO_2 emissions are calculated based on fuel consumption. When the study will be continued; also the transportation costs by vehicle type will be calculated and the results will be represented in the final report.

4. Road wear impacts

Road wear impacts are determined for HCT vehicles and normal vehicles. Analysis is based on the results of the AASHO road test and the other respective tests carried out later.

The road wear impacts of different vehicles can be determined by the following ratio: number of equivalent axles per load [equivalent axles/t] or load per number of equivalent axles [t/equivalent axle].

The results are calculated for different HCT vehicles and normal vehicles when they are fully loaded.

5. Study results

The results include the following factors:

- Power need distribution between rolling and air resistances
- Energy and CO_2
- Road wear
- Transport costs (analysis to be carried out later)

Additionally, some other factors are analysed, e.g. impact of wheel type (single wheels vs. dual wheels) on fuel consumption and CO_2 emissions. Effects on road capacity and vehicle flow on normal vehicles and HCT vehicles are not studied, but it is recognised that two normal vehicles take more road space than one HCT vehicle. Development of modal split in Finland (modal split and the relevant changes in transport legislation in Finland 1970 – 2016) is indicated, too.

5.1 Power need distribution between rolling and resistances

Figure 2 indicates the power need distribution between rolling and air resistances of loaded and unloaded vehicle.

For an loaded vehicle, the role of rolling resistance is dominant, see figure 2. For an unloaded vehicle the rolling resistance is dominant when speed is low, but the air resistance force becomes dominant when speed is more than 70 km/h, figure 2. The powertrain losses are excluded, because they are not relevant for the study.

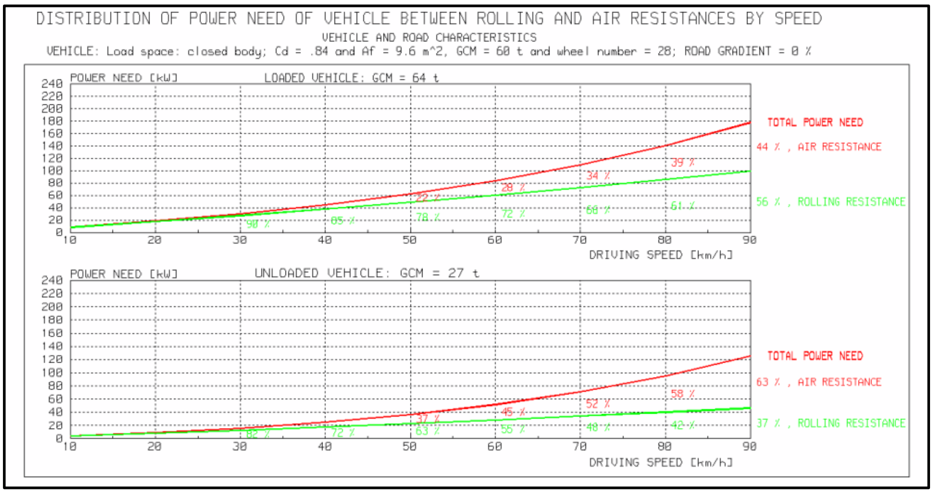

Fig. 2 Distribution of power need of vehicle between rolling and air resistances by driving speed

5.2 Fuel consumption and CO_2 emissions

Figure 3 shows fuel consumption per traffic product unit [vehicle km] of vehicles by mass and wheel number. The ellipse symbols for vehicle 1, 6 and 7 indicate fuel consumption without container masses.

Figure 4 shows relative fuel consumption per transport product unit of normal and HCT vehicles. Figure 4 is based on table 1. Table 1 shows fuel consumption of normal and HCT vehicles by vehicle pair and loading type. Appropriate transport product unit is l/load space meter (abbreviated l/LS m in table 1) for volume goods and thus for vehicles 1, 2, 3, 6 and 7. The unit l/tkm is appropriate for mass goods and for vehicles 4 and 5.

Fuel consumption per transport product unit of the HCT vehicles is from 9 to 26 percent lower than the fuel consumption of normal vehicles, depending on the vehicle pair and loading type. The same reduction applies to CO_2 emissions. Fuel consumption of vehicle 6, which has dual wheels in its semi-trailers, is higher than fuel consumption of vehicle 7, which has single wheels in its semi-trailers. High loading level is an important factor concerning transportation economy and CO_2 emissions of vehicles, and especially, of HCT vehicles.

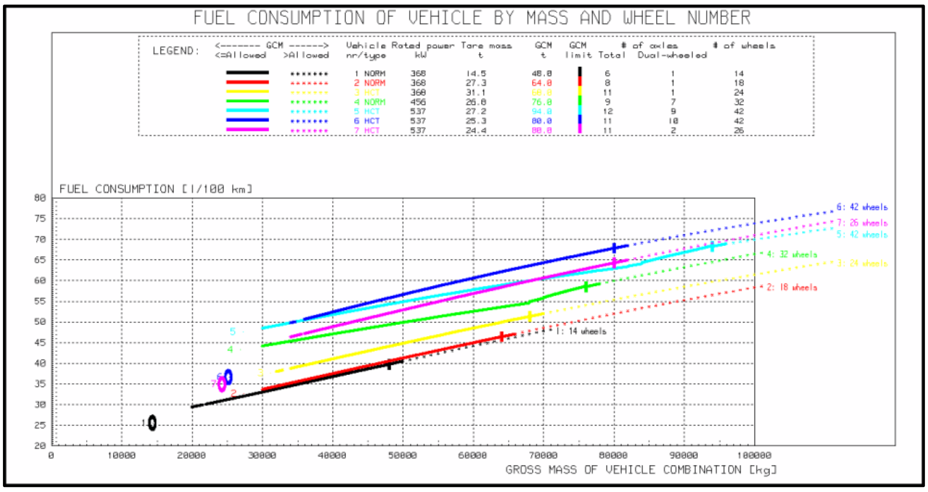

Fig. 3 Fuel consumption per traffic product unit vs mass and # of wheels

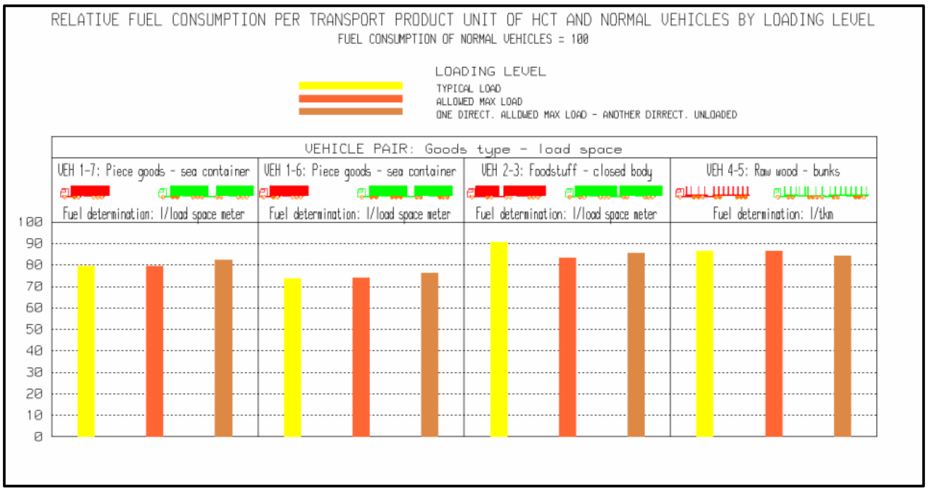

Fig. 4 Relative fuel consumption per transport product unit of normal and HCT vehicles by vehicle pair and loading level

Table 1. Fuel consumption of normal and HCT vehicles by vehicle pair and load type

Vehicle	Load type (level)	Tare	Load	GCM	Length of LS	Fuel consumption		
#		t	t	t	m	l/100 km	l/100 tkm	l/LS length m
1	Typical load	14.5	25.5	40.0	12.6	36.8	-	2.91
6	Typical load	25.3	24.0	49.3	24.4	56.4	-	2.31
	Index (6 vs. 1)	1.74	94	1.23	1.93	1.53	-	.79
1	Maxim load	14.5	32.5	47.0	12.6	39.4	-	3.12
6	Maxim load	25.3	33.8	59.1	24.4	60.3	-	2.47
	Index (6 vs. 1)	1.74	1.04	1.26	1.93	1.53	-	.79
1	(0- + maxim load)/2	14.5	16.3	30.8	12.6	33.5	-	2.65
6	(0- + maxim load)/2	25.3	16.9	42.2	24.4	53.1	-	2.18
	Index (6 vs. 1)	1.74	1.04	1.37	1.93	1.59	-	.82
1	Typical load	14.5	25.5	40.0	12.6	36.8	-	2.91
7	Typical load	24.4	24.0	48.4	24.4	52.3	-	2.14
	Index (7 vs. 1)	1.68	.94	1.21	1.93	1.42	-	.74
1	Maxim load	14.5	32.5	47.0	12.6	39.4	-	3.12
7	Maxim load	24.4	33.8	58.2	24.4	56.2	-	2.30
	Index (7 vs. 1)	1.68	1.04	1.24	1.93	1.43	-	.74
1	(0- + maxim load)/2	14.5	16.3	30.8	12.6	33.5	-	2.65
7	(0- + maxim load)/2	24.4	16.9	41.3	24.4	49.3	-	2.02
	Index (7 vs. 1	1.68	1.04	1.34	1.93	1.47	-	.76
2	Typical load	27.3	15.0	42.3	21.3	38.4	-	1.81
3	Typical load	31.1	20.0	51.1	27.6	45.3	-	1.64
	Index (3 vs. 2)	1.14	1.33	1.21	1.30	1.18	-	.91
2	Maxim load	27.3	38.0	65.3	21.3	46.9	-	2.20
3	Maxim load	31.1	35.0	66.1	27.6	50.7	-	1.83
	Index (3 vs. 2)	1.14	.92	1.01	1.30	1.08	-	.83
2	(0- + maxim load)/2	27.3	19.0	46.3	21.3	39.8	-	1.87
3	(0- + maxim load)/2	21.1	17.5	48.6	27.6	44.2	-	1.60
	Index (3 vs. 2)	1.14	.92	1.05	1.30	1.11	-	.85
4	Typical load	26.8	49.4	76.2	19.7	58.6	1.19	-
5	Typical load	27.2	66.6	93.8	25.5	68.2	1.02	-
	Index (5 vs. 4)	1.01	1.35	1.23	1.30	1.16	.86	-
4	Maxim load	26.8	49.4	76.2	19.7	58.6	1.19	-
5	Maxim load	27.2	66.6	93.8	25.5	68.2	1.02	-
	Index (5 vs. 4)	1.01	1.35	1.23	1.30	1.16	.86	-
4	(0- + maxim load)/2	26.8	24.7	51.5	19.7	50.9	2.06	-
5	(0- + maxim load)/2	27.2	33.3	60.5	25.5	57.9	1.74	-
	Index (5 vs. 4)	1.01	1.35	1.17	1.30	1.14	.84	-

5.3. Road wear impacts

Road wear impacts by the vehicle GCM and other vehicle characteristics, like axle structure and wheel number, are seen in table 2. All HCT vehicles offer low road wear [eq. axle/t] and thus high load per number of equivalent axles [t/equivalent axles], table 2 and figure 5. The vehicles with dual wheels (vehicle 6) have higher load per number of equivalent axle than the vehicles with single wheels (vehicle 7), table 2, and red and green columns in the left part of figure 5. The proportion of vehicles with piece goods and closed body is prevailing in Finland. The proportions of vehicles for raw wood and for piece goods with containers are not high at present but are likely to increase in the future. The distribution of gross combination mass between axles has effect on road wear.

Table 2. Road wear impacts according to the vehicle GCM and other vehicle characteristics

Vehicle	GCM	Load	Axle group	Axles		Wheels	Equiv. axles	Road wear	Road wear comparison by vehicle pair		Load per eq- axle
				total	Sgl wh				Vehicle pair	Index	
#	t	t	#	#	#	#	#	eq. axle/t	#/#	-	t/eq. axle
1	48.00	32.12	3	6	5	14	4.20	0.131	1/1	100	7.6
2	64.00	38.50	4	8	7	18	5.23	0.136	2/2	100	7.4
3	68.00	36.86	5	11	10	24	2.70	0.073	2/3	54	7.3
4	76.00	50.74	4	9	2	32	4.39	0.086	4/4	100	11.5
5	94.00	65.62	5	12	3	42	4.35	0.066	4/5	77	15.3
6	90.00	63.97	5	11	1	42	3.89	0.061	1/6	46	15.8
7	80.00	55.66	5	11	9	26	5.21	0.094	1/7	72	12.2

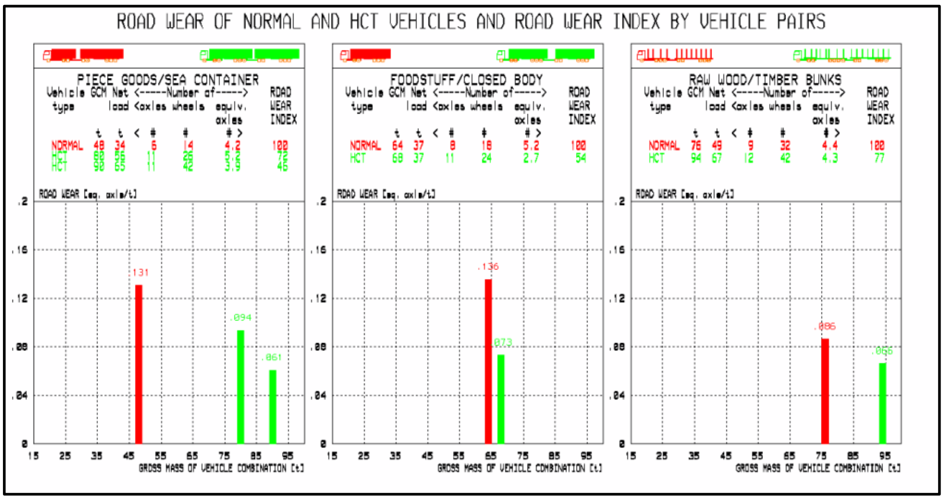

Fig. 5 Road wear by vehicle and road wear comparison by vehicle pairs

5.4. Development of modal split between road, railway and water transportation in Finland

In the years 1970 – 1990 road transportation has increased its share as much as water transportation has lost. The share of road transportation is currently about 2/3. The share of rail transportation has remained constant, at about 1/4. The main reasons to the increase of road transportation are bigger vehicles, as seen in table 3, improvement of the road network and more liberal regulation policy. Share of water transportation has declined substantially during the period 1970 – 1990. It is also worth to note that road transportation is capable to serve in diverse circumstances, from short to long distances and from forest to cities.

Table 3. GCM of road vehicles and modal split of domestic transportation product in Finland in 1970 - 2015

GCM of road vehicles (since year/tons)	<1970/32	1975/42	1982/48	1990/56/60*	1993/60	2013/76
Modal split in year	1970	1980	1990	2000	2010	2015
Road transportation	54,6	57.6	68.0	69.0	65	66
Rail transportation	26.8	26.1	26.6	24.4	25	26
Water transportation (timber floating)	18.6	16.3	10.4	6.6	10	8

*During winter

6. Study limitations

The Finnish Transport Agency (FTA) limited the study to cover only the following aspects: transport economy measured in transport costs, emissions measured as CO_2 and road wear impacts of vehicles measured with number equivalent axle/load [equivalent axle/t] or load per number of equivalent axle [t/equivalent axle]. Additionally, FTA emphasized that the study shall result in basic data which can be used in further calculations of other impacts. That is why the study does not include impacts on safety (especially, risk of overtaking of the HCT vehicle); impacts on bridges (long bridges); overall impacts on fuel consumption and CO_2 emissions; and impacts on future modal split of goods transportation. Road wear analyses based on the AASHO and later road wear tests are valid for roads built according to the road design norms (standards) of Finland.

7. Finland and other EU countries

Vehicle masses and dimensions of road vehicles vary between countries in the EU area. The maximum vehicle masses of vehicle combinations are highest in Finland 76 t. In Sweden, the maximum combination mass is 74 t on a restricted road network in the future. In other EU countries, the maximum vehicle combination masses vary mainly between 40 and 44 t. The length of vehicle combination is 25.25 m in Finland. In Sweden, the maximum length is 24 m, and in some special cases 25.25 m. In other EU countries, the maximum length is 18.75 m for road trains (= truck + trailer). Some countries recognising the benefits of greater vehicles, have changed their legislation (e.g. the Netherlands, Denmark, Norway and Germany).

The fuel economy of the vehicles used in Finland (“FIN” vehicles) is much better than the one of “EURO” vehicles used in other European countries (except Sweden), table 4. It indicates the fuel consumption and CO_2 emissions when the vehicle combination masses are 40 t and 76 t. The running vehicle costs per transport product unit (tkm) of the FIN vehicles are also lower than the respective costs of EURO vehicles. When a certain amount of goods is transported, the EURO vehicles take 1/4 more road space than the FIN vehicles.

One can see that the fuel consumption reduction per transport product unit [tkm] is about 20 %, when vehicle combination mass increases from 40 t to 76 t. Fuel consumption is 1.5 l/100 tkm (Index = 100) for EURO vehicle, but only 1.2 l/100 tkm (Index 80) for FIN vehicle. The respective index is 68 for HCT vehicle combination of 94 t, that is, fuel consumption is reduced by more than 30 %. The reduction of CO_2 emissions is same as reduction of fuel consumption. Finland, which uses GCM vehicles of 76 t has reduced its CO_2 emissions by 20 % in heavy goods transportation compared with other EU countries, which use CGM vehicles of 40 t. Supposing that the HCT vehicles will be introduced for permanent use in Finland, the fuel economy will be very effective and CO_2 emissions will be reduced substantially (about 30 %) in heavy road transportation compared to EURO vehicles.

Table 4. Fuel consumption and CO_2 emissions of "EURO" and "FIN" vehicles

Vehicle	Mass	Load	Fuel consumption		CO_2 emissions	
	t	t	l/100 km	l/100 tkm	g/100 km	g/100 tkm
"EURO" vehicle	40	24	35.7	1.5	951	39.2
Fuel consumption index			*100*	*100*	*100*	*100*
"FIN" vehicle	76	49	58.5	1.2	1556	31.7
Fuel consumption index			*164*	*80*	*164*	*81*
HCT vehicle	94	67	68.3	1.02	1820	27
Fuel consumption index			*190*	*68*	*190*	*68*

Each country decides herself, which kind of transport policy is appropriate. Each country could, however consider, whether the following ideas should be considered in transport policy decisions, especially, now when climate change is an important issue. Transport policy considerations should include:

- minimization of the use of spare resources (especially, energy), and of generation of harmful environment effects (CO_2 and other emissions) and safety risks
- fair distribution of transport services between clients, and recognizing their capabilities to use transport services
- fair competition between producers of transport services without unnecessary regulation, without increasing harm to the environment or customers

Road transportation has dominant role in inland transportation in many countries; it is flexible in space and time to meet demand of different kinds of transport services in diverse areas and circumstances, and its technology is developing further. Each country could consider utilising these benefits by changing legislation and allowing more free regulation policy, and in that way, serve better commerce, their trade and industry.

8. Interim conclusions

The study will continue until end of February 2018. The results mentioned above are interim results. No recommendations are made for the time being. The interim conclusions are:

The HCT vehicles

- substantially reduce fuel consumption and CO_2 emissions per transport product unit
  - in Finland where the allowed GCM is 76 t, the reduction by the HCT vehicles varies between 10 and 25 percent depending on utilisation of possibilities of load capacity
  - in countries where the allowed GCM is 40 t, the reduction by the HCT vehicles could be about 30 percent
- reduce road wear impacts 25 – 50 percent on roads built according to prevailing road design norms
- reduce need of road space 25 – 30 percent, and thus traffic congestion

HCT vehicle combinations are an efficient way to reduce CO_2 emissions. Our research indicates that the road wear impacts of HCT vehicles are much less than that of normal vehicles. It is evident that the HCT vehicles reduce transportation costs, too, as the transport companies have already informed us, but further study will confirm that and indicate numeric reduction figures.