IMPORTANCE DE LA SOLIDITE DES PNEUS ET DE LA PROFONDEUR DES NERVURES SUR LES PNEUS D'HIVER POUR VEHICULES LOURDS

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RESUME

La solidité du pneumatique, ainsi que la profondeur des nervures dans les pneus d'hiver; constituent des éléments décisifs pour la conduite de véhicules lourds en période hivernale. L'utilisation de pneus inappropriés peut contribuer aux accidents de la route, particulièrement lors de conditions hivernales sévères, avec chaussées glissantes. Il y a cependant à ce jour un manque de documentation sur les performances des pneus pendant les périodes de grand froid. Pour cet article, des données sur l'usure des pneus de camions ont été collectées sur plusieurs hivers, en se focalisant sur l'état des parties latérales du pneu (solidité de la gomme), la profondeur des nervures; ainsi que le pays d'origine.

Deux campagnes de terrain ont été réalisées. Le premier test, effectué en 2011, avait pour principaux sujets d'étude la dureté des pneus et la traction. L'expérience a été exécutée selon les standards norvégiens utilisés pour tester les chaînes d'hiver pour camions. Deux véhicules sont liés l'un à l'autre par un câble sur lequel est accroché un dynamomètre électronique. Le véhicule à l'arrière freine tandis que le véhicule testé, à l'avant, tente de se maintenir à une vitesse constante. La force de traction maximum est enregistrée au moment du freinage. Cinq pneus, dont les âges, nervures, et dureté sont différents, ont été testés, avec et sans chargement, sur de la neige compacte. Les meilleurs résultats sont obtenus pour les pneus à la gomme la moins dure, et avec les nervures les plus profondes: ces pneus présentent des forces de traction 10 à 15% plus élevées que les autres pneus.

Le second test, réalisé en 2013, visait à investiguer l'existence ou non d'une corrélation entre distance de freinage et dureté du pneu. Trois pneus, dont la dureté et la profondeur des nervures sont différentes, ont été testés. Il a été observé que la distance de freinage varie de façon significative entre les pneus. L'association "gomme relativement souple" et nervures profondes donne les meilleurs résultats (courtes distances de freinage).

Les deux tests concordent donc dans leurs conclusions, qui plaident en faveur de pneus à la gomme relativement souple, avec des nervures profondes. Des pneus présentant de telles caractéristiques ont une distance de freinage réduite, ainsi qu'une meilleure traction, deux points cruciaux en matière de sécurité routière.

1. INTRODUCTION

1.1 Heavy traffic in Norway

Every winter trucks get stuck in steep slopes in Norway causing significant traffic congestions and potentially dangerous situation. Particularly in the county Møre and Romsdalen, The Norwegian Public Roads Administration (NPRA) often face these problems because of steep parcels and hard winter conditions her. Inspections over several seasons show that about 20% of heavy traffic here comes from non-Nordic countries [1] [4]. During the winter there are many accidents involving heavy vehicles and statistics show that non-Nordic vehicles are over-represented in these accidents [2]. While there may be several reasons for this, one possible explanation could be that the foreign vehicles have tires that are not optimal for harsh winter roads conditions that are more common in Nordic countries, compared to the rest of Europe. The transportation companies have economic benefits of using tires that last longer, rather than providing good grip on snow and ice. Tires that last longer appear to have harder rubber to prevent excessive tire wear, and this may reduce the traction capacity on snow and ice [3].

2. OBJECTIVE

Measuring the hardness and tread depth of tires may predict if trucks will have sufficient traction to come safely up slippery slopes. If this is true, the NPRA can performs checks during difficult winter conditions and allow only trucks with satisfactory winter tires to continue, while trucks on poor quality winter tires have to wait until the conditions improve. It appears to be little full-scale data available that reports on the effect of tire hardness and tread depth on the traction and braking of heavy vehicle tires.

The objective of this paper was to provide more knowledge on the effect of hardness and tread depths on the traction of tires. This is done by addressing these research questions:

- Are there are differences in the tire tread hardness between Nordic-registered trucks and non-Nordic (or non-Norwegian) registered trucks.

- If rubber hardness and tread depth affect traction for heavy vehicles.

- If rubber hardness and tread depth affect stopping distances for heavy vehicles

3. EXPERIMENTAL METHOD

Three field experiments were conducted. The first experiment was a control of heavy vehicles in the Romsdalen valley, where the goal was to determine the difference in tire hardness between Nordic and non-Nordic heavy vehicles. The next experiment was a traction test, where the total pulling force of heavy vehicles was measured. The last experiment was a brake test, where both heavy vehicles with and without load, as well as passenger car performed a brake test with different tires.

3.1 Shore-value on Norwegian trucks vs. foreign trucks

Random heavy trucks were stopped over three days at Horgheim control station and over two days at Otta control station in Romsdalen during the winter of 2011. The nationality was registered and the shore-value measured. A handheld shore meter was used to measure the shore value on five different places at each driving wheel. The measurements were performed immediately after stopping the trucks. Tread depth was also measured, and pictures of the tire was taken. A total of 112 trucks were inspected at Horgheim, of which 71 were Norwegian trucks and 23 were from countries outside the Nordic countries. In Otta a total of 32 trucks were inspected, there were only 1 Norwegian truck and in all 7 Nordic trucks among these.

3.2 Traction

One test vehicle and five different tires were tested in February 2011. The experiments were performed for two slopes in Romsdalen with an average rise of 7%.

Figure 2. Measurement of pulling force

As seen in Figure 2, the experiment was carried out according the Norwegian standard for testing truck snow chains (NS 5960:2010). Two vehicles are tied together with a wire and a scale. The vehicle at the back is braking while the test vehicle in front is trying to maintain steady speed. Maximum traction (pulling) force is registered while the rear vehicle slowly brakes from 10 km/t to full stop. Five tires with different ages, tread depths and hardness's were tested in both loaded and unloaded conditions on a steep and level ground. The road condition was compact snow and sunny weather for both slopes. The air and road surface temperature was from -6 °C at the start of the day and -2 °C at the end of the day at one of the slopes, and the air temperature went from -1 °C at the start of the day to 9 °C at the end of the day at the second slope, and the road temperature from - 1°C to 1°C The test setup is shown in figure 3.

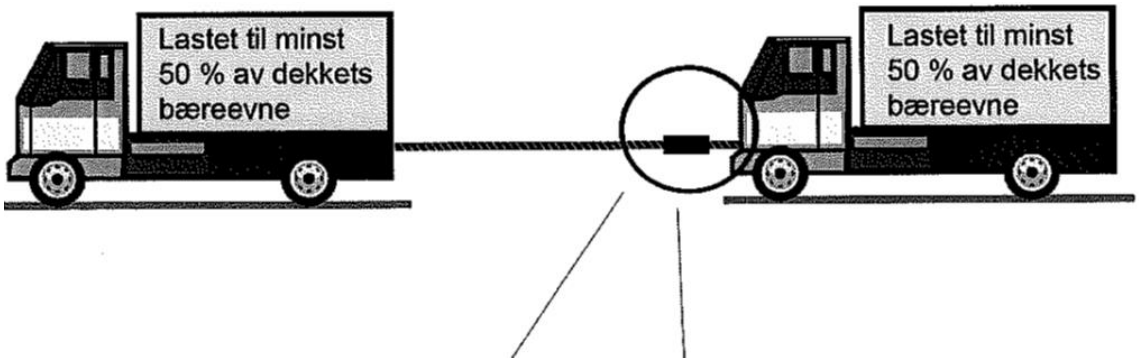

Figure 3: Test setup, Norwegian standard (NS 5960:2010). Test truck in front and braking truck behind.

Change of gears shall be made during the test and the greatest traction is documented. Measurements of traction between the test vehicle and braking vehicle was recorded with a precision scale of a Straight Point Radio Link Plus with measuring range up to 25 000 kg and a resolution of 5 kg. Traction is logged two times per second. The data was of wireless transmitted to a PC. Each test was repeated five times and each time the maximum pulling force was recorded. The highest and lowest readings was removed and mean value is calculated of the remaining three tests, the difference between the remaining three test results shall not exceed 30%. . A TWO friction measuring device was used to document the frictional conditions during the tests.

3.3 Braking distance

Figure 4. Truck reaches 70 km/t

The field experiment was conducted at Trysil airport in February 2013. Two trucks and two passenger cars were used in the experiment. One truck and one passenger car were used as the reference vehicle, while the other truck and passenger car were used as the test vehicle. The truck was run both with and without load. The reference vehicles were used to control friction conditions throughout the day. Test vehicles were run with two different types of tire sets. One of the tire sets would represent good winter tires and the other would represent poor winter tires. The good tires had more tread depth and lower shore-value (softer rubber) compared to the poorer tires.

The vehicles passed a marked point at 70 km/h. At this point the driver pushed the braking pedal to maximum braking until the vehicle was completely stopped. Braking distances were measured with GPS additionally with a manually measuring tape. The GPS was a Race Logic VBOX3i with 100 Hz recording rate. It provided the exact speed throughout the deceleration. Each tire set was run five times on each test car. The roadway consisted of snow / ice cover, with friction around 0.30.

Braking distances must be corrected for changes in friction conditions throughout the day. This was done by calculating a correction factor *c* using the friction measurements of the reference vehicle .
Braking distance is adjusted by a correction factor *c*. It is based on a reference friction (μ_{ref}), which is defined as the average of the reference tire friction experienced throughout the day. The correction factor c is then:

Correction factor $c = \mu_{ref} / \mu_{\text{(the reference car experienced friction)}}$

Calculated friction value from the GPS measurements is the average value of the five runs with each tire, where the minimum and maximum value are removed. Calculation is as follows:

$$\mu = \frac{v^2}{2g * L}$$

The conversion from m/s to km/h, and get the following expression for the coefficient of friction, μ:

$$\mu = \frac{V^2}{254{,}3 * L}$$

where v = Vehicle speed before braking [km/t]
L and v are directely read from the GPS-measurments.

4. ANALYSE AND RESULTS

4.1. Shore-value on Norwegian trucks vs. foreign trucks

Table 1. Summary of average shore value on Norwegian vs. foreign trucks stopped at Horgheim and Otta control station.

Horgheim	Shore value	Tread depth [mm]
Norwegian trucks	63,8	12,8
Foreign trucks	63,7	12,5
Non-Nordic trucks	63,4	12,7

Otta	Shore value	Tread depth [mm]
Norwegian trucks	61,2	-
Foreign trucks	63,2	-

Table 1 shows the average Shore value of the trucks that were stopped. At Horgheim control station the average shore-value was 63.7, with an average standard deviation of 1. The lowest value measured was 55.8 and the highest value was 70, both were non-Nordic. Average value for tread depth was 12.7 mm. Norwegian trucks had an average value of 63.8 in shore, with a tread depth of 12.8 mm. Foreign trucks had an average value of 63.7 in shore, and an average tread depth of 12.5 mm. Trucks registered outside of the Nordic countries had an average value of 63.4 in shore with a tread depth of 12.7 mm.

Measurements conducted on Otta control station shows an average hardness of 62.6 in shore. Norwegian trucks had average hardness of 61.2, while foreign trucks had wheels with a hardness of 63.2. The range of trucks tested at Otta is admittedly quite small (32 pc).

The controls show no significant differences in shore-value or tread depth on Norwegian trucks versus foreign trucks.

4.2 Traction

Figure 5 shows the traction as a function of shore value for the different test runs. Each line represents one test run. The marks (crosses, boxes, etc.) represent each tire. There is a tendency of declining traction with increasing tire hardness (shore-value) in all. Tire 2 (shore-value 64.8) and tire 3 (shore-value 70) shows quite similar traction values although the difference in tire hardness is 5-shore units. Tire 2 was a used tire, but tire 3 was new. All the tires, with the exception of the tire 5, had good pattern depth and was relatively new. This test show that the best tire had between 11% - 16% better traction than the tire with lowest traction.

The test runs consisted of various situations (8 ton and 10 ton axle loading, single and twin tires) to create some variability in the testing conditions. Despite this variability there is a consistent trend of decreasing traction with increasing shore value. The magnitude of the decrease may vary, depending on the conditions but the overall picture is that the traction decreases with 15-20 % when the shore value increases with 10 units.
Preliminary results show that the assumed best tires have about 10-15 % higher traction force unloaded and up to 30 % higher when loaded.

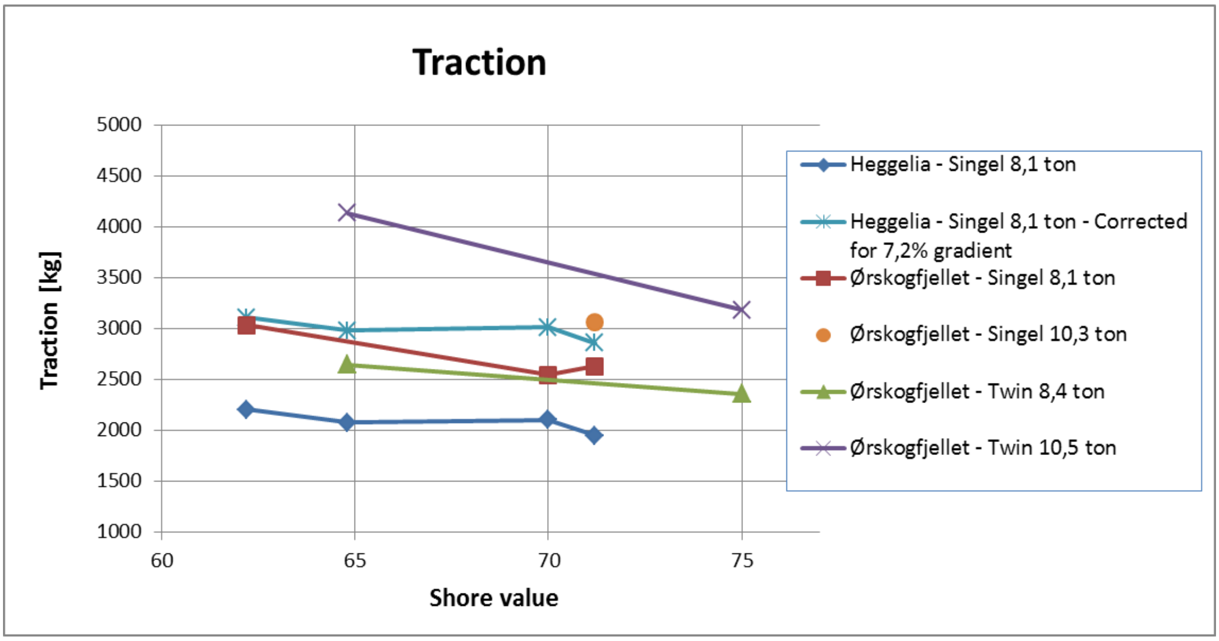

Figure 5. Traction and shore value

4.3 Braking distance

The braking distances for the truck and the personal car are shown in figure 6 – 11.
Figure 6 shows the braking distance for truck without cargo day one, and figure 7 for day two. Tire A had shore value 64/65 and tread depth 15/20, tire B had shore value 67,8/69,6/70 and tread depth 5,5/8/7.

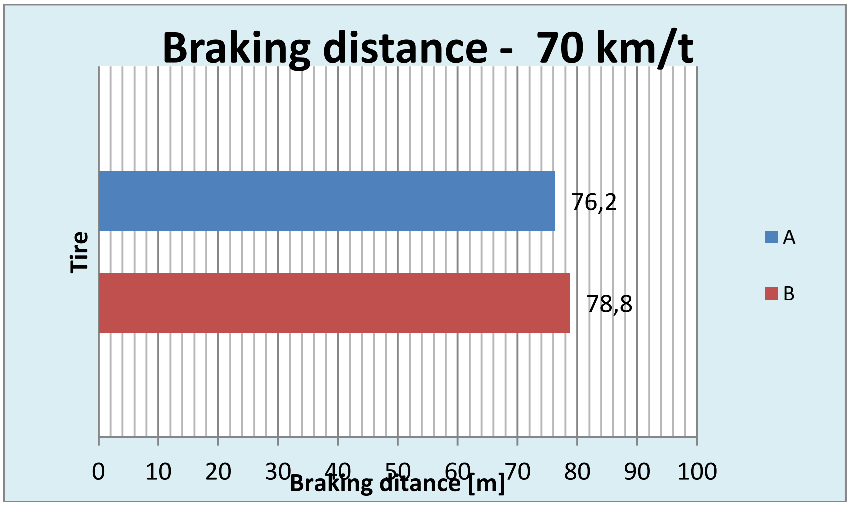

Figure 6. Braking distance for empty truck, tire A vs. tire B. Day 1.

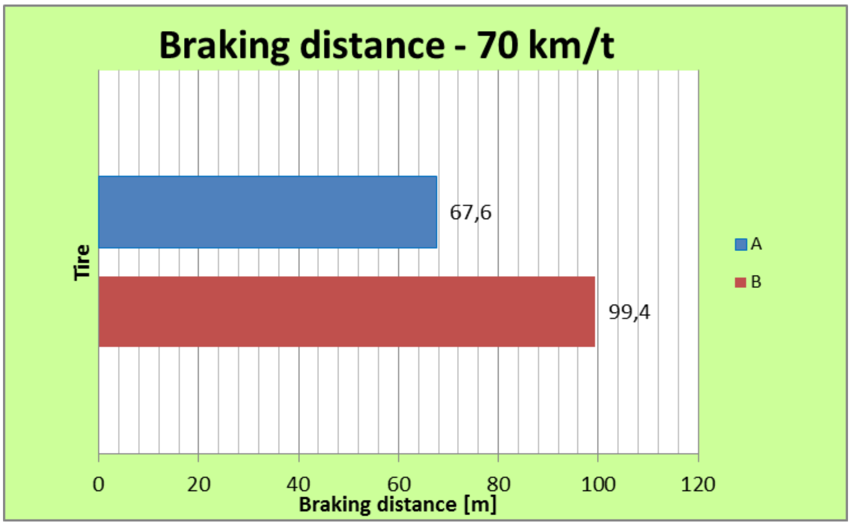

Figure 7. Braking distance for empty truck, tire A vs. tire B. Day 2.

Figure 8 shows the braking distance for truck with cargo day one, and figure 9 for day two. Tire A and B is the same tire as in figure 6 and 7.

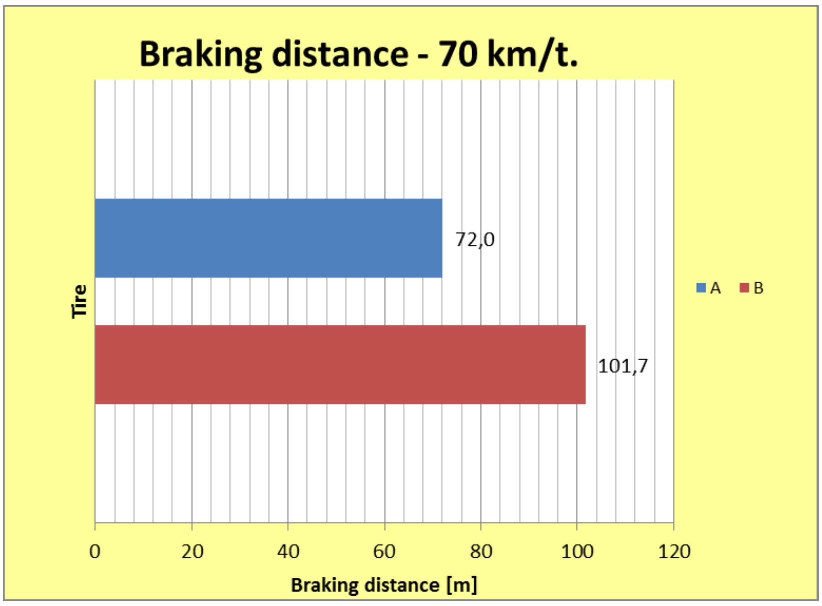

Figure 8. Braking distance for truck with cargo and 70 km/t. Day 1.

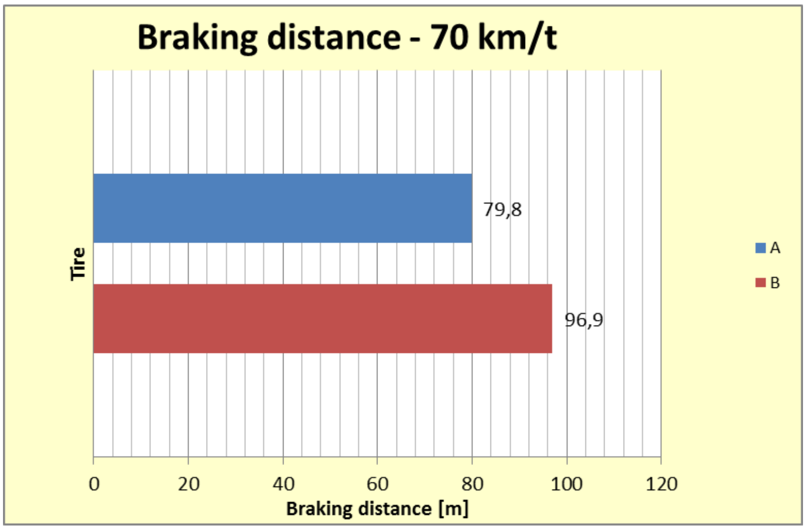

Figure 9. Braking distance for truck with cargo and 70 km/t. Day 2.

Figure 10 shows the braking distance for passenger car day one, and figure 11 for day 2. Tire C and D is the different tires sets that was used. Tire C had shore value 48/48 and tread depth 8/8 (front/back), tire D had shore value 64,3/64,3 and tread depth 4/5 (front/back).

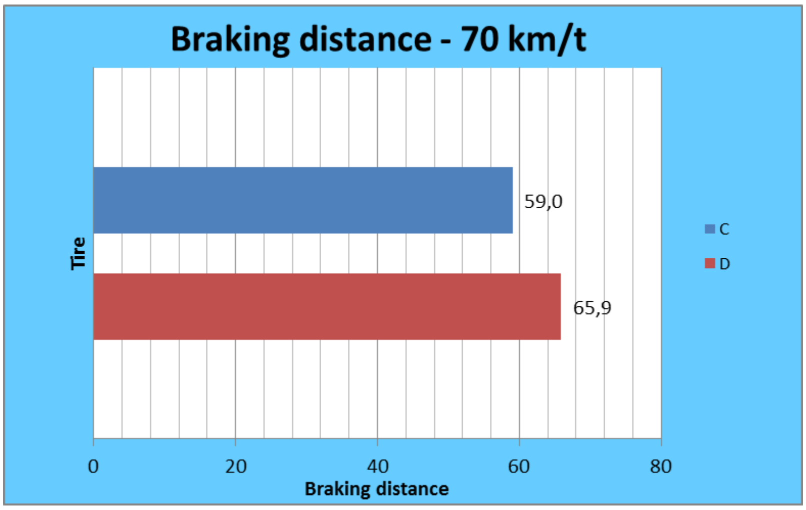

Figure 10. Braking distance for passenger car at 70 km/t. Day 1.

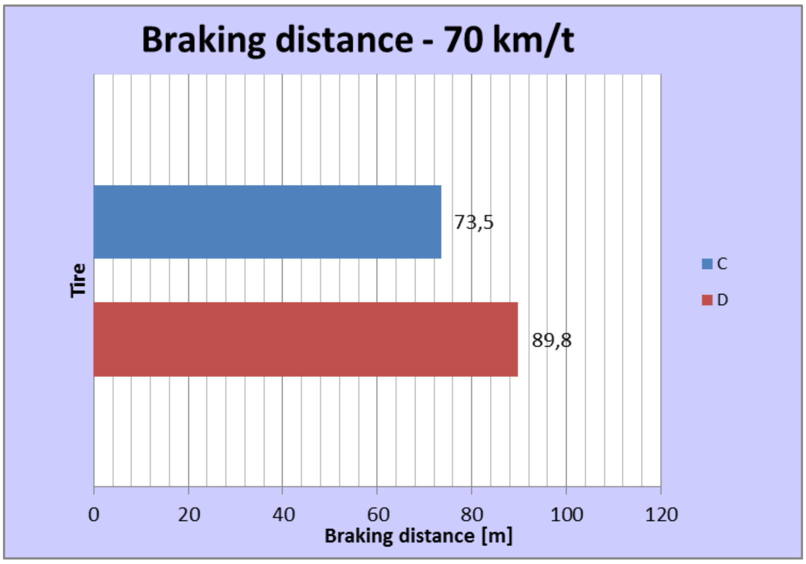

Figure 11. Braking distance for passenger car at 70 km/t. Day 2.

A significance analysis was performed on the results, with a confidence level α = 0.05 corresponding 95% confidence intervals. There were significant differences in braking distance between the tires. The tire with lowest shore-value and most tread depth had the shortest stopping distance. For the trucks, the difference in average 24% longer braking distance on the bad tires, and about 31% when it was loaded. This corresponds to 17.2 meters and 23.4 meters. The poor tire on the passenger car had on average 18% longer braking distance than the good, the length amounted to 11.6 meters.

The experiment has shown the importance of good winter tires versus bad. It must be added that the experiment did not indicate whether it was the tread depth or the shore-value that is the reason for the large difference in braking distance.

The table below shows a summary of braking distances for truck (with and without cargo) and passenger car at 70 km/h. Values are average between day 1 and day 2. The difference in braking distance between good and bad tires are shown both in meters and percentage.

Table 2. Braking distance with different tread depths and shore value.

Tire	Braking distance			Tire data	
	meter	Δ (meter)	Δ (%)	Tread depth, average (mm)	Shore value
Truck, A	71,90	17,20	23,9	17,5	64,5
Truck, B	89,10			6,8	69,1
Truck with cargo, A	75,90	23,40	30,8	17,5	64,5
Truck with cargo, B	99,30			6,8	69,1
Passenger car, C	66,25	11,65	17,6	8	48
Passenger car, D	77,90			4,5	64

The column Δ% shows the difference in braking distance between the tire with low shore value and high tread depth and the tire with higher shore value and low tread depth for the truck empty and with cargo and the passenger car. The truck is experiencing lager differences than the passenger car. The difference in braking differences with the different tire sets was for the truck 23.9 %, and for the passenger car it was 17.6%. The truck also experienced lager differences when it is loaded, 30.8% with cargo compared with 23.9% when it was empty.

5. DICUSSION

The first experiment showed that there on was not a big difference in average shore value between Nordic and non-Nordic trucks. This could mean that several things. One reason can be that not only non-Nordic trucks drive on tires with hard rubber. Another option is that the average statistics covers that there are some "bad individuals", although the truck with highest shore value was from Denmark.

The second experiment showed that the pulling force was higher for the softer tire in all the tests. Although the magnitude of the difference varies from test to test, there is a clear decreasing of pulling force with increasing shore value. The difference in shore value was not more than 10 – 12 units, but this increases the pulling force with 10 – 30 %. This means that even small differences in shore value, may give the extra sufficient force to crawl up the slippery slope. So – tire hardness seems to have an impact in the ability for trucks to crawl up the slope. For run number 5 and 6, the difference in pulling force (35 %) was larger than the difference in axle load (20 %). This result was unexpected; however the data is too limited to draw firm conclusions.

At the last experiment different tires were used on trucks and passenger cars and braking distance was measured. The difference between the two set of tires used on trucks was 10 mm tread depth and 4.6 units shore-value in average. The difference between the two sets of tires on the passenger car was 4 mm tread depth less and the difference in shore-value was 16. The truck experienced greater differences in braking distance between the two tires then the passenger car, even though the difference in shore value between the tires were larger for the passenger car. This may indicate that tread depth has greater impact on braking distance the shore-value.

Two causes for longer breaking distance when the tire has less tread depth and harder rubber is likely:

- Less tire tread makes it more difficult to get the edge and the sipes (division of the rubber block into thinner pieces) into the snow.
- A higher shore value indicates a harder rubber, which will have more difficulties draping itself around surface roughness in the snow.

But less tread depth will, as explained above, give longer braking distance because the response is stiffer. And when the response becomes stiffer, there is less deformation in the rubber normally the tire. Thus - low tread depth may provide experienced stiffer rubber for the tire, which is the same as occurs when shore value becomes lower. Shore value may therefore be depending on a certain tread depth.
There are mainly two reasons for incising braking distance when the bad tires are used.
• Higher shore-value - providing stiffer response. The rubber are unable to use all pits and peaks in the rough ice and snow cover.
• Less tread depth - also stiffer response because the shoreline as the pattern represents the tire is lower, i.e., much the same happens when a spring steel is shorten.

6. CONCLUSIONS

Friction is important in terms of accessibility and especially for road safety. Tire hardness together with tread depth and tread pattern, is expected to be one important factor with regards to winter operations of trucks. The main findings of this study are:

Measurements during the control of random heavy trucks in Romsdalen showed no difference in shore-value between Norwegian, Nordic and non-Nordic trucks.

With respect to traction, the results of the experiments show a clear tendency for tires with a higher hardness (shore-value) to reduce traction and thus reduce accessibility. The tire sets with lowest shore value and most tread depth had between 11% and 16% better traction than the tire with lowest traction. Increase was greatest with tires with high tread depth and soft rubber and the axle inside the tire's maximum load capacity. Tires with low pattern and hard rubber appear to have significantly poorer ability to mobilize traction also when axle load are increased. The results of these experiments show that the weight of the rear wheels is of great importance for accessibility.

With regards to braking distance, the results indicate that lower shore value and higher tread depth gives shorter braking distance for both truck and passenger car.

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