Reducing the Rut Depth of a Thin-paved Road by Controlling the Driving Lines of Heavy Trucks

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ABSTRACT: Deepening of ruts due to heavy trucks driving constantly the same driving line on thin-paved roads is a significant problem to road maintenance. The problem is worsening as truck weights and truck traffic volumes are increasing. Especially rapidly ruts can develop during the thawing period of seasonal frost. As rut depth increases, longitudinal cracks may develop and the bearing capacity of road deteriorate also outside of the thawing period, since ruts are gathering rainwater and cracks allow it infiltrate into the road structure. There are plenty of this kind of thin-paved low-volume roads, which may be occasionally exposed to intensive heavy truck loading, when for instance timber is harvested on the region.

In an earlier study funded by the Finnish Transport Infrastructure Agency it was noticed that a heavy truck can uplift road surface even at distance of 1.5 to 2.0 m from the driving line. Therefore, it was decided to test if it is possible to reduce rut depth by controlling the driving lines of heavy trucks. Loading tests were carried out using seven-axle log trucks weighing 64 tons instantly after the frost thawing. The vertical movements of road surface were measured using two displacement transducers, one located at the wheel path and the other one 0.5 m apart from it, while the development of rut depths on a longer road section was monitored using a laser scanner.

The results clearly indicated that by controlled variation of driving lines it was possible to restore a major part of rutting developed by the preceding heavy truck overruns. This observation has great practical significance regarding autonomous traffic when in the worst scenario all heavy vehicles are guided to the same driving line.

KEY WORDS: rutting recovery, thin-paved road, driving line, autonomous driving, case study.

1 INTRODUCTION

Deepening of ruts due to heavy trucks driving constantly the same driving line on thin-paved roads is a remarkable problem to road maintenance. The problem is worsening as truck weights and truck traffic volumes are increasing. In different parts of the world there are plenty of this kind of thin-paved low-volume roads, which may be occasionally exposed to intensive heavy truck traffic, when for instance timber is harvested on the region. Finland is an example of countries located on climatic region where pronounced seasonal variation prevail and seasonal frost occur. Especially rapidly ruts can develop during the thawing period of seasonal frost. As rut depth increases, longitudinal cracks may develop and the bearing capacity of road deteriorate also outside of the thawing period, since ruts are gathering rainwater and cracks allow it infiltrate into the road structure.

In an earlier study funded by the Finnish Transport Infrastructure Agency it was noticed that a heavy truck can uplift road surface even at distance of 1.5 to 2.0 m from the driving line. (Vuorimies et al. 2018) As a part of larger research, it was decided to test if it is possible to reduce rut depth of a thin-paved low-volume road by controlling the driving lines of heavy trucks.

Width of a road or a lane are known to have an effect on focusing of vehicle on driving lines. Blab and Lizka (1995) have found that vehicle speed and rut depth have a significant impact on the focusing of vehicle driving lines as well. Hjort et al. (2008) observed that the variation of driving lines spreads load and pavement wear over a wider area, thus economic benefit from the variation of driving lines increases with decreasing pavement thickness. Wu and Harvey (2008) modelled Heavy Vehicle Simulator (HVS) test results when driving line was not changed and when it was varied at even intervals from edge to edge and they found that modelling results were near the results of HVS tests. According to some modellings carried out, controlled variation of the lateral position of autonomous vehicles can delay damages and reduce life cycle cost (Chen et al. 2019, Gungor and Al-Qadi 2020).

2 MEASURING METHODS AND SITES

Loading tests were carried out at a low volume road site in Kyyjärvi, in the middle part of Finland. ADT on that site is only about 50. The width of the road is 5.8-6.0 m. Figure 1 shows the layers of road structure. A Soft asphalt layer (SA) is about 30-40 mm thick and the subsoil is peat according to a soil map. The installed transducers were after a gentle curve when normal driving direction was used. On the road there were two visible ruts and longitudinal cracks. The test loadings were carried out in the spring when the frost was assumed to have thawed. Before the loading tests weather had been warm and rainless for more than two weeks. Temperature had varied between 21 and 3°C while average temperature had been 13 °C. However, on May 22nd and 23rd 2018 average temperature was slightly lower. (Finnish Meteorological Institute, 2019).

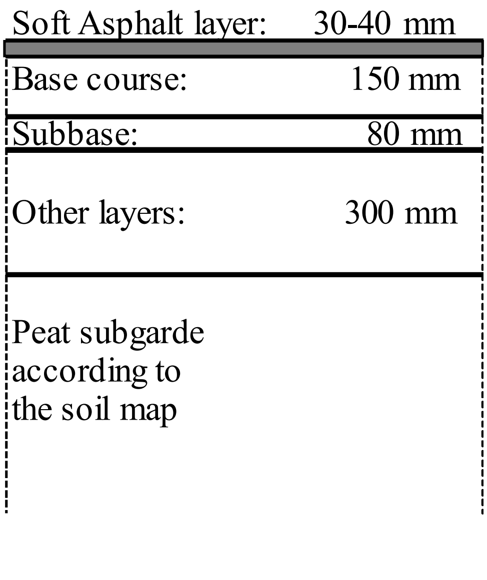

Figure1: Layers of road structure at the test site in Kyyjärvi.

At the test site, two displacement transducers were installed to measure the vertical deflection of the road surface. The transducers were located 1.0 m and 1.5 m from the edge of SA layer so that one was at a driving line called here as primary driving line (PDL) and the other one 0.5 m towards centre line, called here as secondary driving line (SDL) (Figure2). Both transducers were attached between a steel bar, which was installed into stiff subsoil, and underside of the SA layer.

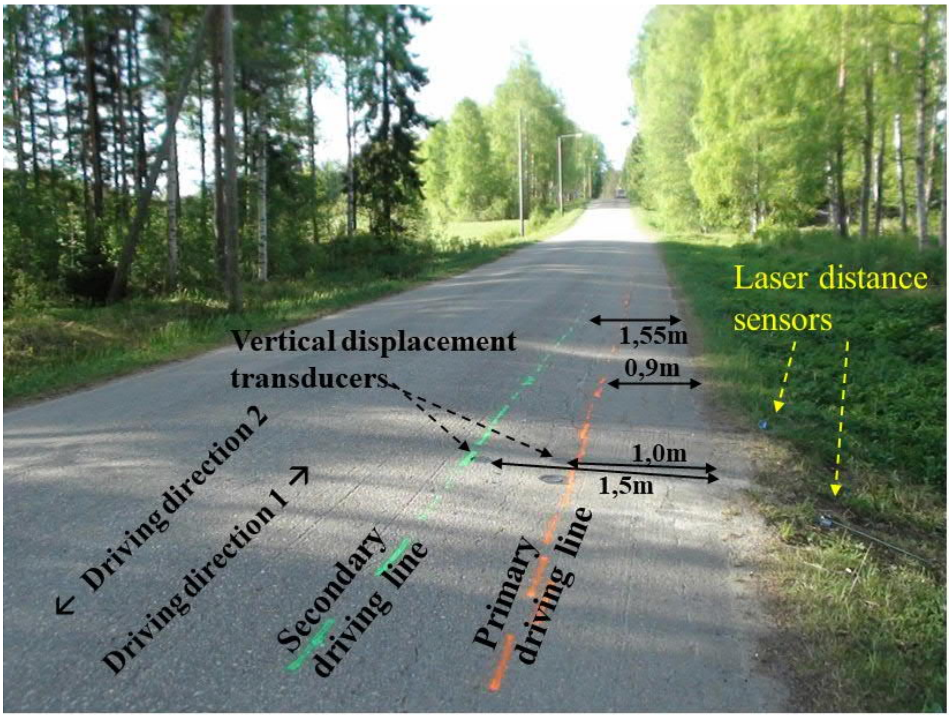

Figure2: Driving lines and directions and transducers at the test site.

Two laser distance sensors with a measuring range of 400 to 5000 mm were installed at the edge of the road. One was in the cross section of the displacement transducers and the other one was at 1.8 m distance after that in the driving direction 1. The laser distance sensor was set to measure the profile of a passing vehicle at a height of approximately 0.35 m from the road surface at wheel path. Passes of the loading vehicles (LV) were also recorded by a video camera.

Roadscanners Oy used a laser scanner of a Road Doctor Survey Van (RDSV) to measure rut depths of the road at the site and their changes after every LV overpass. The principle to determine maximum rut depth is shown in Figure 3. The maximum rut depth was calculated for every meter. An average change in maximum depth of rut was determined on a “short” distance of 10 m around the installed displacement transducers and on a longer distance of about 60 m. The 60 m was assumed to be the length which the LVs drove along the intended driving lines.

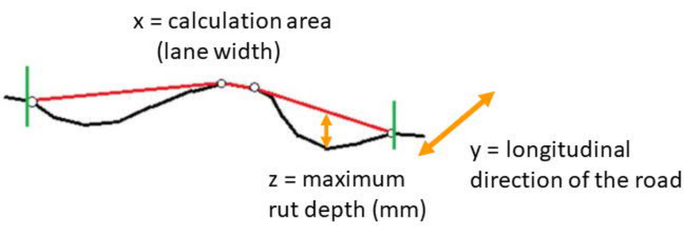

Figure3: Principle of maximum rut depth calculation method in laser scanning.

The LVs were seven-axle trucks weighing 64 tons and their driving speed was about 50 km/h. The steering axle had single tires, while the other axles had dual tires. In addition to the LVs, some other vehicles (cars, trucks, tractors), whose driving lines on the lane could not be influenced, overpassed the measuring area during the monitoring session. The road structure was loaded during two consecutive days. Figure 2 indicated driving lines and directions as well as transducer locations at the test site. In the mornings the LVs were driving along the PDL, which was indicated by painted red line on road surface. In the afternoons the LVs were driving along the green line called SDL, which was 0.65 m towards the centre line of road from the red line. During the first day, one LV overpassed the site about every 20 minutes. On the next day, two LVs were running as close as possible to each other, simulating as closely as possible a 14-axle vehicle combination. Two consecutive LVs overpassed the site at intervals of about 40 min. After the morning loading session there was about one and half hours pause so that the road had time to rest before altering the driving line. The loadings were done in both driving directions. One difference between the two loading test days was that the actual distribution of driving lines was wider on May 23rd than on May 22nd.

3 RESULTS

3.1 Maximum vertical displacements at the test site

Maximum vertical displacement (deflection) of road surface at the test site, when LVs were driving over the transducers was almost 4 mm. Table 1 shows the highest and lowest values of maximum vertical deflection during every loading session at PDL and SDL. On May 22nd maximum axle mass was 10 tons while on May 23rd it was one ton bigger.

Table1: The highest and lowest maximum deflections during each loading session, δ_{max} and δ_{min}, as the LVs were driven along PDL or SDL.

	Primary driving line		Secondary driving line	
	δ_{max}, mm	δ_{min}, mm	δ_{max}, mm	δ_{min}, mm
22.5.2018 morning PDL, 7-axle LV	3.5	3.0	1.9	1.5
22.5.2018 afternoon SPL, 7-axle LV	1.45	1.0	3.1	2.3
23.5.2018 morning PDL, “14-axle” LV	3.9	3.0	1.85	1.65
23.5.2018 afternoon SPL, “14-axle” LV	1.55	0.7	3.05	2.2

3.2 Accumulation of permanent displacements

Figure 4 shows the permanent vertical displacements measured by transducers at PDL (TaPDL) and SDL (TaSDL) about 30 seconds after each vehicle overpass on May 22nd. As the LV drove along the PDL the surface of the road at TaPDL deflected permanently downwards but stayed at about the initial level at TaSDL. The figure indicates also that a tractor with full sand cargo on a 1-axle trailer made a significant permanent deformation at the TaPDL during the pause in between 13:30 and 15:00. The driving line of the LV was changed after the pause. As the LV drove along the SDL the road surface at the TaSDL deflected permanently downwards. At the same time the road surface lifted up at the TaPDL during the first two LV overpasses and stayed at that level after two more LV overpasses.

Two loaded gravel trucks and a tractor with full of sand on 1-axle trailer drove to the direction 1 during the morning loading session. The trucks and the tractor caused the road surface to settle at TaPDL, but the effect was ambiguous at TaSDL. A loaded 8-axle log truck which drove along the other lane to direction 2 caused the road surface to rise at the measuring points. However, it seems that the other trucks did not have significant effect to the trend of measured values during the morning loading session. On the contrary, during the afternoon loading session the tractor with full sand cargo likely did have an effect to the recorded permanent deflections at the measuring points.

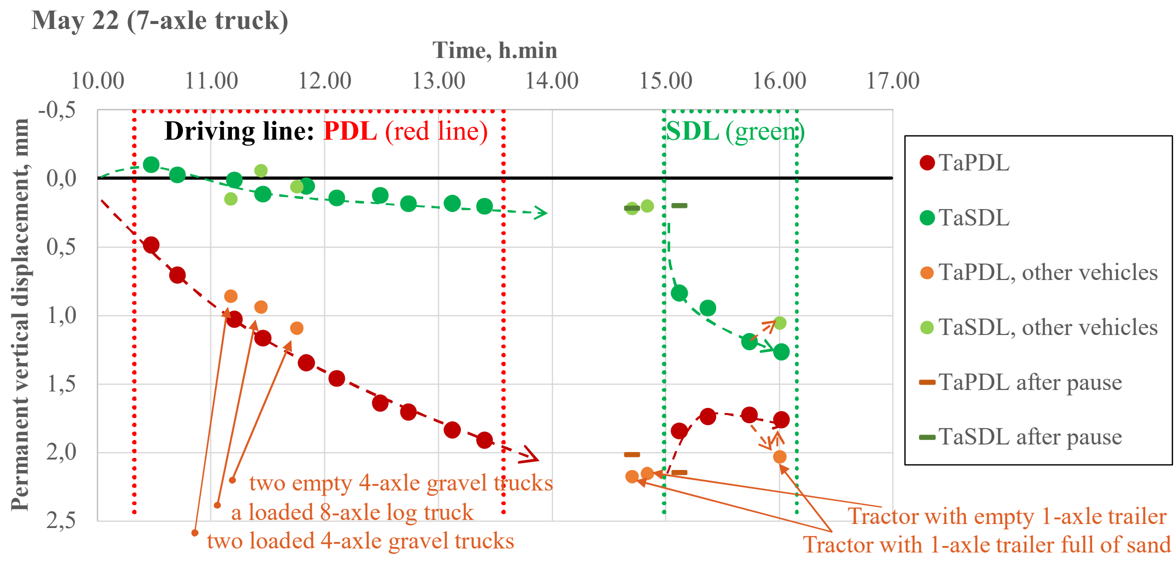

Figure4: Permanent vertical displacements at TaPDL and TaSDL about 30 seconds after vehicle overpasses on May 22nd, 2018. LVs were driving along PDL in the morning and four passes along SDL in the afternoon.

Figure 5 presents differences between the permanent vertical displacements of TaPDL and TaSDL about 30 seconds after each measured vehicle overpass on May 22nd. As the LV drove along the PDL the difference between TaPDL and TaSDL increased denoting that the rut depth also increased. It seems that during the morning loading session other passing vehicles had little or no effect to the difference between the two transducers. The difference was about 1.7 mm after the morning loading session. The figure shows also that a tractor with sand loaded 1-axle trailer caused about 0.2 mm increase of the rut depth slightly before the 1.5 hours pause ends. As the LV was driving along the SDL after the pause the height difference of the road surface between TaPDL and TaSDL decreased significantly. The decrease was about 1 mm after the first LV overpass and 1.5 mm after three LV overpasses. During the afternoon loading session the same tractor with the trailer increased the difference about 0.5 mm, but the next pass of LV returned the difference back to the earlier value.

The above results indicate clearly that the position of driving lines have great effect to development of rut depth and presumably to the shape of ruts on low-volume roads. Figures 4 and 5 indicate also that the first loadings on a new driving line caused the greatest changes to the road surface level at the measuring points.

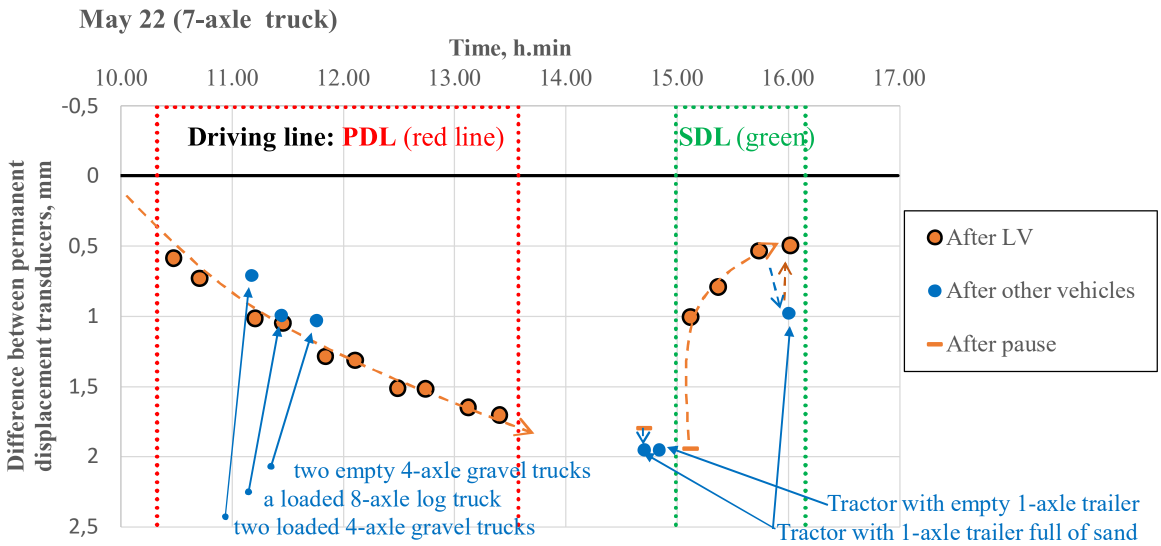

Figure5: The difference of permanent displacements between TaPDL and TaSDL on May 22nd, 2018. LV was driving ten times along PDL in the morning and four times along SDL in the afternoon.

Figure 6 shows permanent vertical displacements of TaPDL and TaSDL about 30 seconds after each measured vehicle overpass on May 23rd. The LV consisted of two 7-axle log trucks running as close as possible to each other. As the LV drove along the PDL the surface of the road at TaPDL deflected permanently downwards and at TaSDL stayed at first at the initial level and then settled a little bit downwards. The figure indicates also that a 9-axle log truck going to the direction 2 uplifted the road surface at the TaPDL. It was the only other heavy vehicle in addition to LV during the day. The driving line of the LV was altered after the pause. As LV was driving along the SDL the surface of the road at the TaSDL deflected downwards. At the same time the first loading caused rising of the road surface at the TaPDL, but the next loadings did not change that level further.

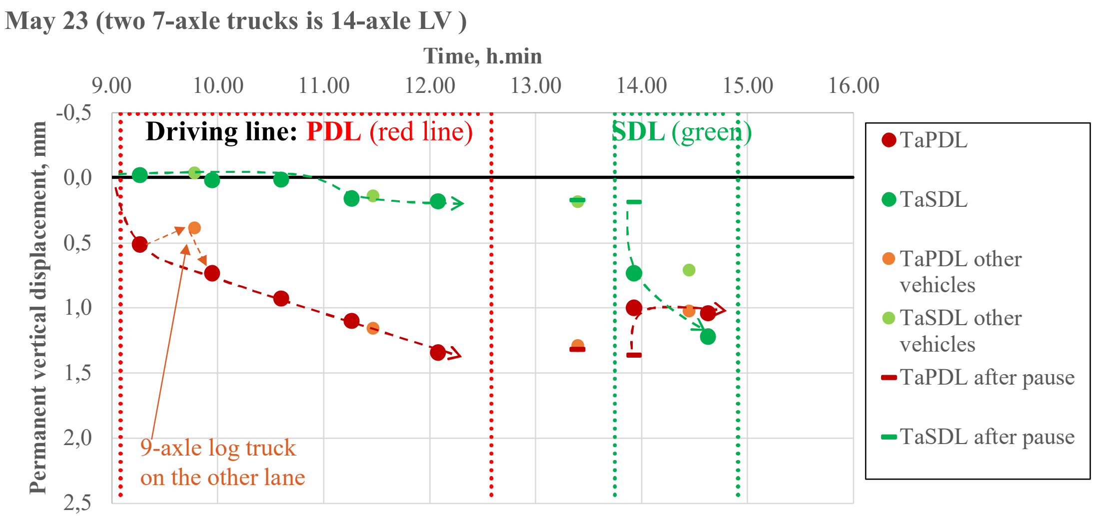

Figure6: Permanent vertical displacements at TaPDL and TaSDL about 30 seconds after vehicles overpasses on May 23rd, 2018. LV was driving along PDL five times in the morning and twice along SDL in the afternoon.

Figure 7 shows difference between the permanent vertical displacements of TaPDL and TaSDL about 30 seconds after each measured vehicle overpass on May 23rd. As the LV drove along the PDL the difference between TaPDL and TaSDL increased denoting that the rut depth also increased. It seems that during the morning a 9-axle log truck had a small effect to the difference between the two transducers. The difference between transducer readings during morning loading session increased about 1.2 mm. As the LV drove along the SDL after the pause the height difference of road surface between PDL and SDL decreased significantly. The decrease was about 1.4 mm after the two LV overpasses thus indicating diminishing of rut depth.

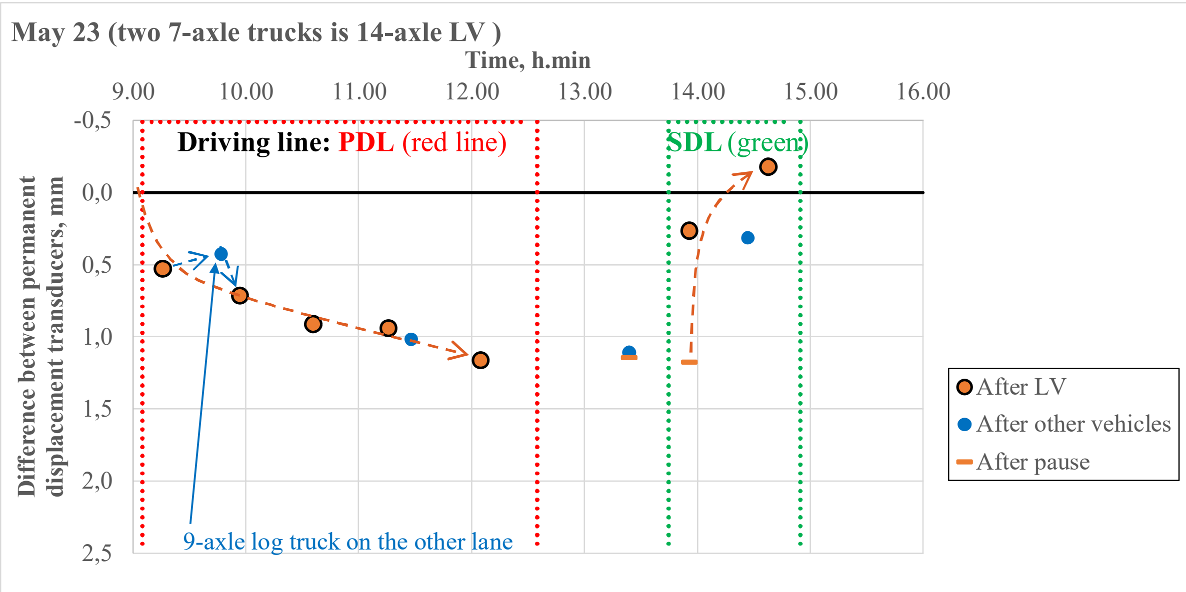

Figure7: The difference of permanent displacements between TaPDL and TaSDL on May 23rd, 2018. LV was driving five times along PDL in the morning and twice along SDL in the afternoon.

As the road and subsoil had thawed shortly before the loading sessions, the LV overpasses also compacted road structure and subsoil, which have been loosened by frost heave. During the two loading test days the road surface settled about 3.5 mm at TaPDL and 2.5 mm at TaSDL. During the night level of road surface settled about 0.5 mm at both measuring points. This might indicate that all of the densification did not happen at once and the loadings might have restarted consolidation of peat under the road.

3.3 Maximum rut depths measured by laser scanning

The figure 8 shows measured maximum rut depths by laser scanner. The red vertical line shows the place of the vertical displacement transducers and white dotted lines show the 60 m distance for studying maximum rut depths. On the studied distance maximum rut depths were about 10-20 mm. Unfortunately, the measurements on morning of May 22nd failed due to technical problems. Figure 8 indicates that the maximum rut depths mostly decreased in the afternoon of May 22nd while the maximum rut depths mostly increased on May 23rd.

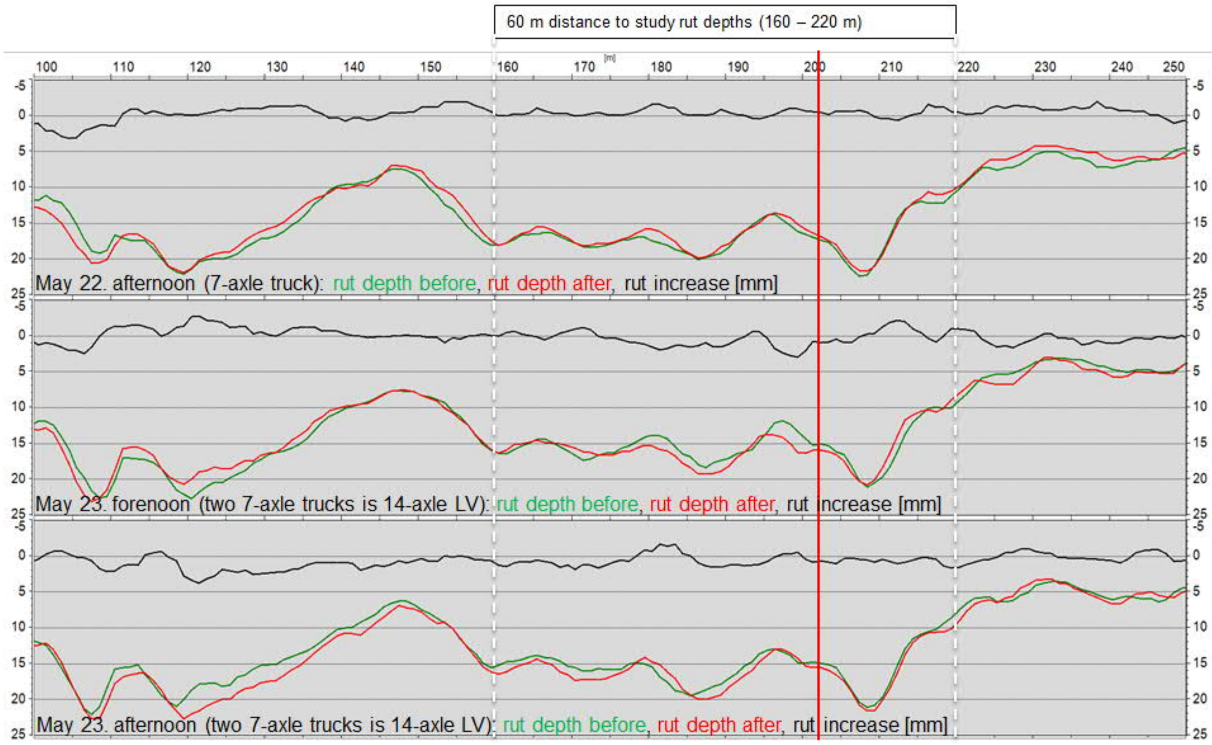

Figure8: Measured maximum rut depths and changes of them during the morning and afternoon loading sessions of May 22nd and 23rd. Vertical red line shows the measuring points of vertical displacement transducers. Note the location of 0-level on the vertical axis.

3.4 Changes in maximum rut depths and in permanent displacements between the transducers

Figure 9 shows average changes of maximum rut depths determined from the two distances and the respective change in permanent displacements between TaPDL and TaSDL on May 22nd. As the maximum rut depths were not available from the morning loading session the initial values for the afternoon session were chosen to be the same as the values of transducers in the beginning of the afternoon. The average change of maximum rut depths determined on a distance of ±5 m from the transducers corresponds well to the change of road surface positions measured using displacement transducers when the LV was driving along the SDL. Also, the average change in maximum rut depths between poles 160 and 220 shows reasonably good compatibility.

Figure 10 indicates average changes of maximum rut depths determined on the distances of 10 and 60 meters and the change of permanent displacements between TaPDL and TaSDL on May 23rd. The average change of maximum rut depths on a distance of ±5 m from the transducers is about the same as the change in the height difference of road surface determined using displacement transducers when the LV was driving along the PDL. However, the average change in maximum rut depths determined between poles 160 and 220 doesn’t indicate that good compatibility. It seemed also that during the loading pause the average maximum rut depths decreased but the height difference between displacement transducers remained at the same level. As the LV was driving for the first time after the loading pause, average maximum rut depths on the distance of ±5 m from the transducers decreased clearly but between the poles 160 and 220 corresponding decrease was small. The next LV increased average maximum rut depths on both distances. Interestingly, at the same time the height difference between displacement transducers decreased.

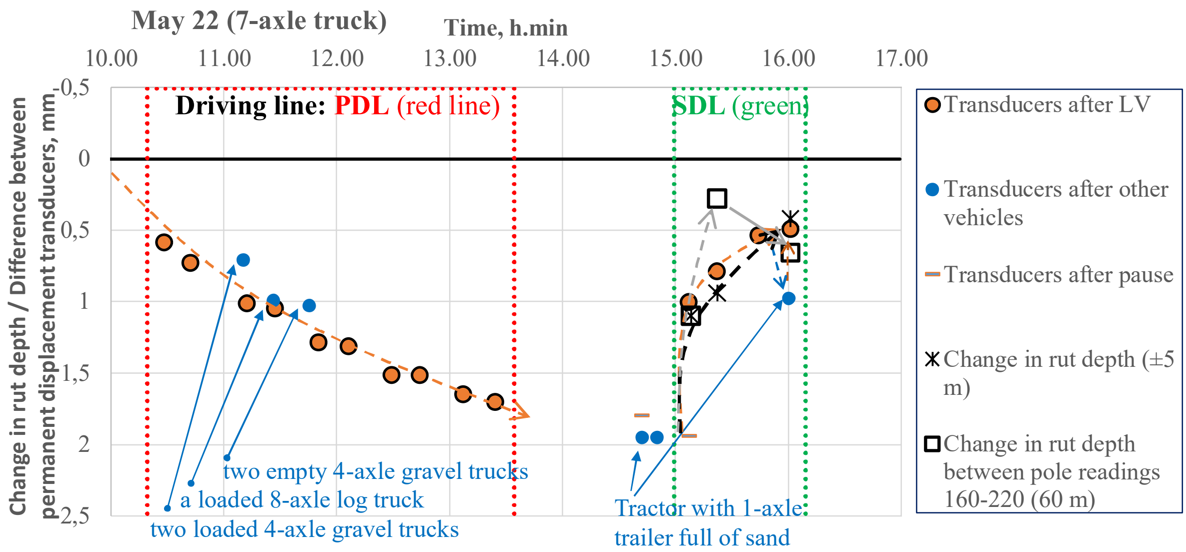

Figure9: The change of permanent displacements between TaPDL and TaSDL and average changes in maximum rut depths for the distances of 10 and 60 meters on May 22nd, 2018. Laser scanner measurement failed on morning. LV was driving along PDL in the morning and four times along SDL in the afternoon.

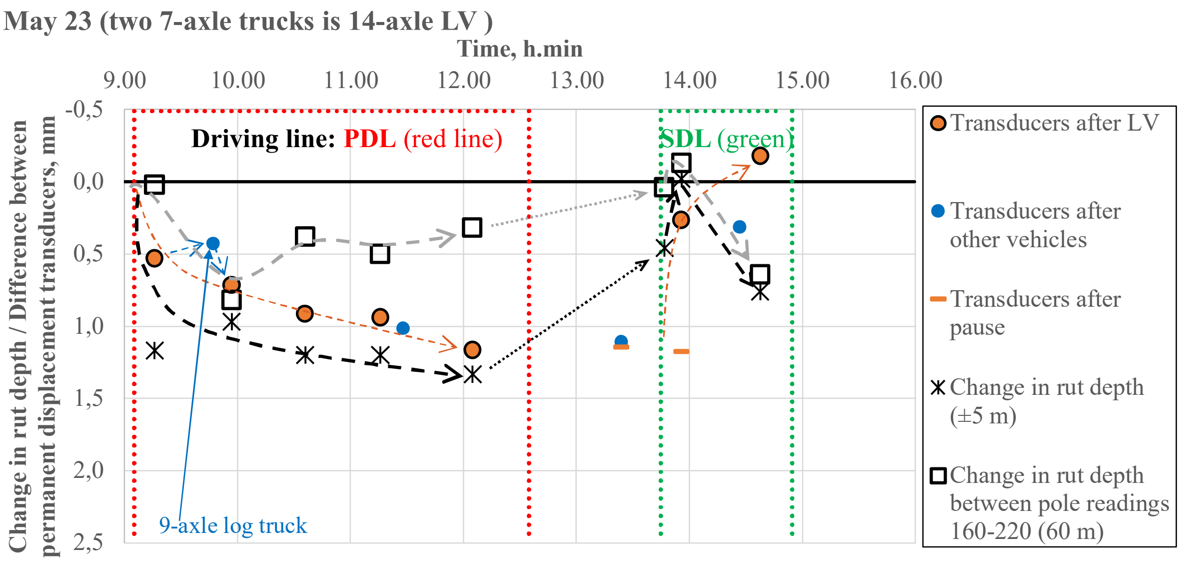

Figure10: The chance of permanent displacements between TaPDL and TaSDL and changes in maximum rut depths determined on the distances of 10 and 60 meters on May 23rd. LV was driving along PDL in the morning and two passes along SDL in the afternoon.

4 DISCUSSION

Figures 9 and 10 show that driving line of a heavy truck can have a significant effect on rut depth on a thin-paved low-volume road. Driving along the same wheel path will likely deepen rut depth the fastest, while altering of driving lines wisely can even decrease rut depths. As SA layer is very thin, almost all deformation occurs in unbound layers and subsoil. When tires of a truck compacts certain areas of a road, other areas might become looser. Driving over the loosened areas of road might restore the earlier situation very quickly. Altering of driving lines also means that grains move continuously against each other, which will smoothen their contact surfaces and thus reduce their resistance against deformations over a long period of time. Optimal minimizing or even decreasing of rut depths on a very thin-paved road, needs in addition to altering of driving lines, also thinking of correct timing to do it. That will be very challenging task and needs more examination.

As the above results clearly indicated, controlled variation of driving lines makes it possible to restore a major part of rutting developed by the preceding heavy truck overruns. Even if the observations presented here were made at a thin-paved low-volume road site, they can give ideas regarding the performance of other roads too, where measurable observations need lots of overruns. When these observations are considered, guiding all the vehicles to drive along the same driving line will have an additional damaging effect on roads. Therefore research theme for the best practises for altering the driving lines of heavy vehicles to minimize the damages of roads will be needed. However, it is not sure, if the best practises are the same if asphalt or unbound layers have a dominant effect on bearing capacity of road? Naturally the width of road and road safety will also set their own restrictions for the possible solutions.

5 CONCLUSION

The loading tests carried out showed that the driving line of a heavy truck can have a significant effect on rut depth on a thin-paved low-volume road. The results indicated also clearly that by controlled variation of driving lines it was possible to restore a major part of rutting developed by the preceding heavy truck overruns. Sometimes altering driving line can even decrease earlier rut depth. Results also showed that the first overrun along a new driving line will have greatest effect on rut depth. Planning of driving lines will have a significant role on the life cycle costs of roads especially when autonomous driving becomes more common.

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