REDUCED PAVEMENT SERVICE LIFE
- CAUSES AND COSTS

J. GRANLUND
Expert in Road
Technology at
WSP Sverige AB.
Obtained MSc. in
Civ. Eng. at
University of
Luleå.

Abstract

Pavement loads and road wear have become hot topics in Sweden, due to both an increase of gross combination weight to 74 tonnes and a governmental investigation on a new road wear fee for heavy vehicles. To balance the governmental investigation, the road haulage industry made an independent expert investigation on causes and costs of reduced pavement service life. This paper summarizes the expert report into English. A literature study on factors that cause shortened pavement life cycle explain causes of non-traffic related damages. The annual total cost for maintenance of paved state roads in Sweden was in this investigation split into repair of traffic load related damages and of non-traffic related damages. A reference cost for road damage from heavy vehicles was estimated, by dividing costs for traffic load related damages with heavy vehicle traffic work. Using the *Fourth Power Law*, the road damaging effect of eleven heavy vehicle combinations were calculated while considering also axle and tyre configurations. Finally, the reference cost for repair of traffic load related damages was distributed to each vehicle combination. Hereby it became possible to compare the estimated vehicle specific cost for road damage versus the fee proposed by the governmental investigation. The ratio between state accounted cost for road damage from heavy vehicles and state proposed fee for road wear is about 1:8. This showed that the proposed fee is very high, being a tax rather than representing true cost coverage. After the industry reported this finding, the government withdrew their investigation on a fee.

Keywords: Pavement and Bridge Loading, Lifecycle Management. Pavement Deterioration. Policies and Vision. Road Wear Taxation.

1. Introduction

Sweden is by area Europe´s fifth largest country, but has only 22 inhabitants per km^2. While Sweden is heavily industrialized, it is still a very rural country with long transport distances. From this context, it is logic that Sweden has a long tradition of increasing the capacity of heavy goods vehicles (HGV´s) used in domestic freight. The increase of Gross Weight limits in Table 1 reflects this.

Table 1 – Historically Allowed Gross Weights on Public Roads in Sweden

Year	1920	1930	1944	1952	1968	1974	1990	1993	2015
GW [ton]	10	12	24	33,5	37,5	51,4	56	60	64

The weight of a vehicle or trailer including the maximum load that can be carried safely and legally on the road is called gross vehicle weight. This weight is also known as permissible maximum weight, or maximum authorized mass. The total weight of the truck/tractor unit plus the trailer/-s and payload is called gross combination weight (GCW). This may also be called gross train weight.

The national limit for GCW in Sweden was in 2015 increased from 60 to 64 tonnes. In 2017/2018 the GCW limit was increased furthermore, from 64 tonnes to 74 tonnes, see Transportstyrelsen (2015) and the new Swedish law SFS 2017:360. Parallel to these actions, the Swedish government made an investigation on a new fee for 12+ tonnes heavy vehicles, due to the road wear they cause (SOU 2017:11). These activities made pavement loads and road wear to national hot topics.

The Swedish road haulage industry anticipated an unfairly high fee for HGV traffic, and contracted WSP Sverige AB for an expert investigation on causes and costs of reduced pavement service life. The aim of the latter investigation, reported in Swedish by Granlund & Lang (2017), is to describe the societal benefits of various measures on both heavy vehicles and road infrastructure based on knowledge from scientifically valid credentials. This paper summarizes the Swedish expert report from WSP into English.

2. Research Approach

A literature study was made on the influence of factors that cause shortened pavement life cycle, regardless of differences in traffic load. For example, abrasion from studded winter tyres on passenger cars, deicing with road salt resulting in road surface becoming wet and thus more prone to wear, climate, ageing / oxidation of bituminous binders, imperfections in the road construction (e.g. insufficient frost insulation) and maintenance (e.g. poor drainage), as well as delayed maintenance. The findings from the literature study explain causes of non-traffic related damages.

In the economic analysis, the annual total cost for maintenance of paved state roads in Sweden was split into cost for repair of traffic load related damages and cost for non-traffic related damages. The split was made with a ratio of 25 % cost for repair of traffic-related damages and of 75 % cost for repair of non-traffic related damages. This ratio was determined in earlier research by the Swedish Transport Administration. A reference cost for pavement

damage from heavy goods vehicles (HGV:s) was estimated, by dividing the cost for repair of traffic load related damages with the measured traffic work done by HGV:s as well as by the average number of Equivalent Standard Axle Load per HGV (1.3 $ESAL_{10}$).

With the *Fourth Power Law* (FPL), the road damaging effect (No. of $ESAL_{10}$) of eleven HGV combinations were calculated. The impacts of axle and tyre configurations were calculated with a version of the FPL modified by the Danish Road Directorate. This version of FPL is presented in Equation 1 below. Full tables for constant values are available in both Hjort et al (2008) and Granlund & Lang (2017). Finally, the reference cost for repair of traffic load related damages was distributed to each of the eleven HGV combinations, by multiplying with their number of $ESAL_{10}$. Hereby it became possible to compare the estimated vehicle specific cost for road wear to the fee proposed by the governmental investigation.

$$\boldsymbol{ESAL_{10}} = \sum_{i=1}^{n} \sum_{j=1}^{m_i} \frac{A_i * B_{ij} * C_i * D_{ij}}{m_i} \left(\frac{P_{ij}}{5}\right)^4 \tag{1}$$

Where:
$ESAL_{10}$ = number of 10 tonnes standard axles of the HGV in <u>the wheelpath</u>.
n = number of axle groups.
m_i = number of axles within axle group i.
A_i = Constant that on strong roads accounts for the number of axles within group i, as well as the distance between the axles within the group. A_i is a load reduction constant for roads with strong base layer, where only primary rutting in the paved concrete layers is considered. No reduction is made for roads with a weak base where also secondary rutting typically occur; a permanent deformation in the subgrade or in unbound layers below the asphalt.
B_{ij} = Constant that accounts for the axle´s tyre fitment. B_{ij} = 1.0 for dual tyres and ranges for single tyres from 1.25 to 4 depending on their width.
C_i = Constant that takes the type of suspension of axle group no. i into account; C_i = 1.0 for leaf, parabolic and coil springs; C_i = 0.95 for air, rubber, hydraulic and oil.
D_{ij} = Constant that accounts for the air pressure of the tyres on axle no. ij. Baseline is D_{ij} = 1.0 for all tyres with 7 Bar. The largest D_{ij} value is 1.4 and it applies for single tyres with 9 Bar on weak pavements.

3. Results

GCW is decisive for the load-dependent damage on bridges. The main HGV properties for traffic load damage on road pavements and within the pavement however, are axle loads and the configurations of axles and of tyres, together with tyre pressure. According to earlier research by the Swedish Transport Administration, about 75 % of the costs for shortened pavement life cycle depends on other factors than traffic load. Abrasion from studded winter tyres on passenger cars, climate, ageing / oxidation of bituminous binders, osmotic pressure caused by deicing road salt in paved layers with heterogeneous void content, imperfections in the road construction and maintenance as well as delayed maintenance are examples of factors that cause shortened pavement life cycle, regardless of differences in traffic load. An example of result from asphalt construction error is documented on photo from the paving day in Figure 1. The material separation damages being built into the pavement will reduce the pavement service life with several years.

Figure 1 – Reduced Pavement Service Life by Bad Asphalt Construction Practice

Meeting the industry's need for heavy transports effectively, while taking into account the total road damage from all road transport traffic work, requires that vehicle road damage per ton payload is low. The standard vehicle combination for domestic long haul road freight in Sweden has since 1990 been 60-tonnes rigs with 7 axles, having an average load of 8.6 tonnes/axle. After the revision of Swedish HGV´s weight regulation in 2015, some of these rigs became allowed to operate with up to 64 tonnes gross combination weight. This gives an average load of 9.1 tonnes/axle. 74 tonnes GCW is allowed on HGVs in Sweden since 2017, while during 2018 the first opening of limited parts (about 12 per cent) of the state road network for 74 tonnes rigs will take place. Most 74 tonnes rigs will have either 9 or 11 axles. With 9 axles, a fully loaded 74-tonner will have an average load of only 8.2 tonnes/axle. The articulated 74 tonnes vehicle with 11 axles will average as little as 6.7 tonnes/axle. Already these coarse calculations strongly indicate that the 74-tonnes reform will reduce road damage, compared to transports using traditional Swedish 60-tonnes rigs.

The report by Granlund & Lang (2017) commences with identifying a reference cost for road damage from HGV´s, with year 2015 as baseline. The annual cost for maintenance and repair of state paved roads in Sweden, as accounted by the Swedish Transport Administration, was 0.36 Billion € in year 2015. The cost was converted from 3.64 Mdr SEK with the exchange rate 1 SEK = 0.10 € on Dec 31, 2015. In year 2014, the corresponding cost was 3.52 Mdr SEK and in year 2016, it was 3.66 Mdr SEK. This shows that the cost for maintenance and repair of state paved roads is constant. The cost in year 2015 was split into costs for repair of

traffic load related damages and of non-traffic related damages. The split was made with a ratio 25 % cost for repair of traffic-related damages and 75 % cost for repair of non-traffic related damages, determined in earlier research by the Swedish National Road Administration. Hence, the cost for repair of traffic-related damages was determined to 0.091 Billion € / year. This cost was distributed to the measured traffic work of 6.5 Billion vehicle-kilometers on state roads done by HGV:s in year 2015, as well as by the average number of 1.3 Equivalent Standard Axle Loads per HGV (for the true mix of unladen / laden HGV´s operating on the roads). Both the traffic work 6.5 Billion vehicle-km and the 1.3 $ESAL_{10}$ values have been measured and stated officially by the Swedish Transport Administration. This calculation lead to a reference cost for repair of traffic-related damages of 0.011 $€/ESAL_{10}*km$ and 0.014 €/km for the average HGV on Swedish state roads.

Granlund & Lang (2017) then used the *Fourth Power Law* (FPL) as per Equation 1 to calculate the road damaging effect of each of the eleven HGV combinations seen in Figure 2. Note that the calculations were not made on tax weight per vehicle (listed in Figure 2), but on max legal weights for the vehicle combinations and distributed on axle groups, axles and wheels as per industry practice. An example is that road damage from HGV type 4 was not calculated for 18 + 24 = 42 tonnes, but for the combination´s legal limit 40 tonnes. Another example is that road damage from HGV type 11 was not calculated for 25 + 24 + 18 + 24 = 91 tonnes, but for the combination´s legal limit 74 tonnes. See the Swedish full report for details.
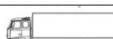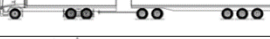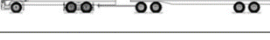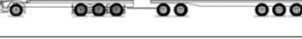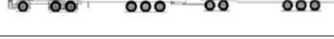

	Heavy Goods Vehicle Combination	Tax Weight [ton]
1		7.5 (No Vignette < 12 ton)
2		18
3		26
4		18 + 24
5		25 + 24
6		25 + 24 + 20
7		25 + 18 + 24
8		25 + 36
9		25 + 20 + 24
10		32 + 18 + 24
11		25 + 24 + 18 + 24

Figure 2 – The Heavy Goods Vehicle Combinations

An example of road damage calculation is given in Table 2, made for the 40 tonnes EU semitrailer with two-axle tractor unit (HGV type 4). Note that $ESAL_{10}$ and $ESAL_{10}$/Payload are calculated per a single wheelpath, following the terms of use for Equation 1.

Table 2 – Calculation of Road Damaging Effect for HGV type 4 on Strong Road

	Load [ton]	*Tyre [mm]*	*A_i*	*B_{ij}*	*C_i*	*D_i*	*$ESAL_{10}$*	*$ESAL_{10}$/ Payload*
Kerb Weight	*15*							
Max Payload	*25*							
Max GCW	*40*							
Steer Axle Load	*6.5*				*0.95*			
Steer Tyre	*3.25*	*385*		*1.79*		*1*	*0.304*	
Drive Axle Load	*11.5*				*0.95*			
Drive Tyre	*5.75*	*2 x 295*		*1*		*1*	*1.662*	
Triple Axle Load	*22*		*1.9*		*0.95*			
Trailer Wheel	*3.67*	*385*		*1.79*		*1*	*0.934*	
Vehicle in Total Over a Wheel Path							*2.90*	*0.232*

Finally, Granlund & Lang (2017) used the reference cost 0.011 €/$ESAL_{10}$*km derived above, and the road wear factors for the eleven HGV combinations defined in Figure 2, to calculate the cost for road damage from each HGV type. The results are reported in the chart in Figure 3, relevant for costs on roads with a proper base layer, where no secondary rutting occur in unbound layers and in the subgrade. (Also, a chart for weak pavements is presented in the full report). For some HGV-combinations, the road damage costs were calculated for single mounted wide base tyres as well as for dual mounted tyres. The chart reports three values per HGV type; Road Repair Cost [€/km], Road Repair Cost [€ / payload ton * 100 km], and, on the right side value axle, Payload [ton]. Most road freight by weight on Swedish roads (68 %) are made by HGV´s driving less than 100 km, see Lastbilstrafik 2016. Hence, 100 km is set as reference. The most interesting value in the chart is Road Repair Cost per payload ton & 100 km (RRC). It varies near tenfold, from 0.043 to 0.36 € between the HGV combinations.

By far the highest Road Repair Costs per payload ton & 100 km are caused by HGV type 2 (an 18 tonnes two-axle rigid truck), and by HGV type 4 (the 40 tonnes EU semitrailer with two-axle tractor unit). All vehicle combinations with total weight of 44+ tonnes yield moderate RRC. The lowest Road Repair Cost per payload ton and 100 km is achieved by a 74 tonnes high capacity modular vehicle, operating on properly constructed pavements. Vehicle combinations with 60 and 64 tonnes total weight cause as much RRC, or more, on the pavement (per payload ton and 100 km), as 74 tonnes rigs.

HGV type 5 (an EU-semitrailer rig with three-axle tractor unit) turns out superior, regarding Road Repair Cost, to the road-aggressive two-axle tractor unit with 11.5 tonnes on the drive (HGV type 4). Note that this is despite 4 tonnes higher weight for HGV type 5.
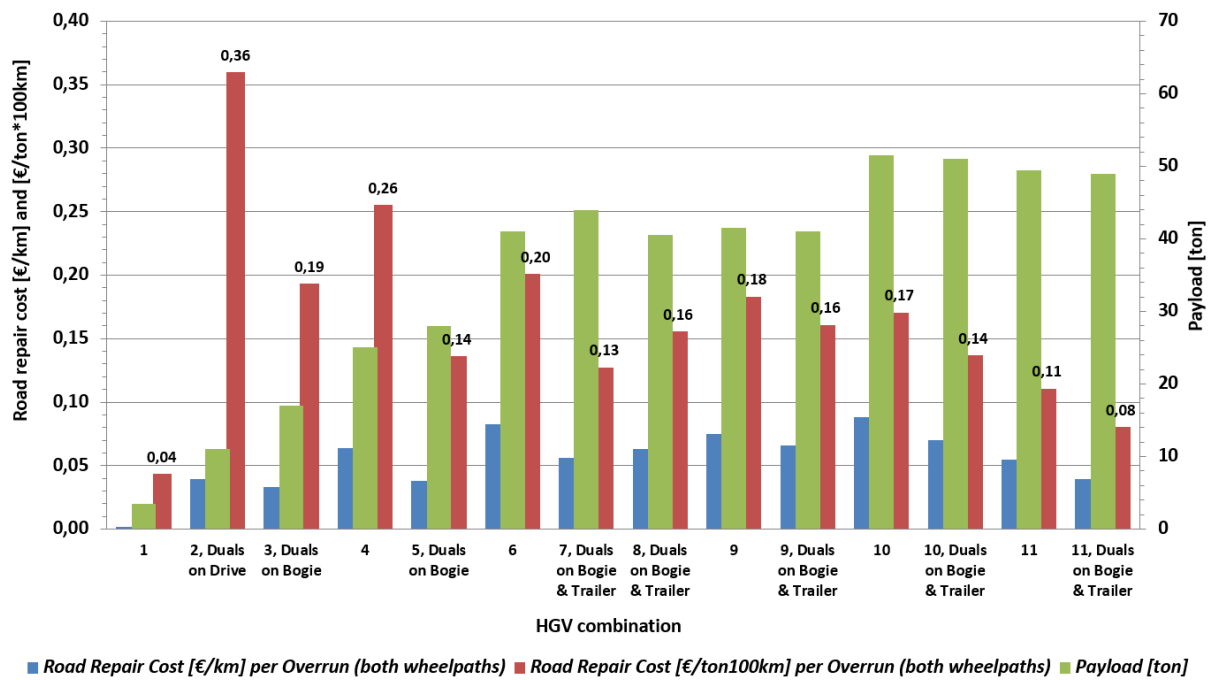
Figure 3 - Cost for Repair of Road Damage by HGV´s on Properly Built Roads

The above-mentioned cost of 0.014 €/km is to be compared against the average fee for road wear of 0.11 €/km proposed by the governmental investigation. This show that the ratio between state accounted cost for road damage from HGV´s and the governmental proposed fee for road wear from HGV´s is about 1:8.

Granlund & Lang (2017) also show that road damage costs increases considerably (up to 50 %) on weak road constructions (not showed in this paper), compared the same transport on properly built roads. This indicate a potential for societal long-term economic savings, by reinforcing undersized pavement structures in order to reduce costly road damages. Weak pavements mainly exists among low volume roads.

Data from the Swedish road network shows that in terms of cost for road repair, a heavy truck cause road deterioration costs equal to what 16 passenger cars do, due to the extensive use of studded winter tyres on passenger cars causing abrasion of not only ice but also asphalt concrete or Portland cement concrete in the road surface. 1:16 is a considerably lower ratio than what is sometimes described based on calculations with the fourth power law, whereby the damage from a single truck is equated with damage from up to 100 000 cars. *Note: The FPL is not valid for road damage from passenger cars at all, as they are out of the use conditions for FPL. Furthermore, FPL does not consider abrasion from studded car tyres.*

4. Discussion

Granlund & Lang (2017) assume that the cost for road damage on state roads is reflected by the costs for maintenance and repair (M&R) of these roads, as officially accounted by the Swedish Transport Administration. If the M&R works are significantly overfunded or underfunded, this assumption can be misleading. As in many other countries, there is an

endless discussion on backlog in the condition of the road network in Sweden. However, the condition parameters that are being used in Sweden (International Roughness Index, Rut Depth and Pavement Edge Deformation) show a constant condition over years. Swedish Transport Administration´s annual reports also show that also the accounted cost on M&R is constant over the years. Hence, the interpretation is that there is currently no obvious neither increase nor decrease in the backlog of condition (roughness, rutting and edge deformation) on the state paved road network. Therefore, the above-mentioned assumption by Granlund & Lang seems reasonably valid.

The results by Granlund & Lang (2017) show that costs for repair of pavement damage per HGV on the state road network in Sweden is more than twice for an EU work horse on long-haul (two-axle tractor with semitrailer; total weight 40 tonnes), compared to an European Modular System vehicle carrying considerably more goods (total weight up to 74 tonnes) distributed on more axles and wheels. Furthermore, the 40 tonnes EU-workhorse is easy to overload on the drive axle, although loaded within legal GCW. For example, unloading 7 tonnes from the rear of a semitrailer legally loaded with 25 tonnes can move the semitrailer´s center of gravity forward, so that the truck tractor drive axle load increases from legal 11.5 tonnes to illegal 13 tonnes. Unloading making the vehicle overloaded may not be intuitive, but it is nevertheless a fact for semitrailers. Weigh-In-Motion measurements on Swedish state roads confirm that the frequency of overload on the drive axle (resulting in axle weight 12 to 16 tonnes) is exceptionally high for this type of HGV combination. The drive overload can be solved by replacing the two-axled truck tractor with a bogie axled unit. This means replacing HGV type 4 by HGV type 5. From road damage point of view, such a development may very well be economically beneficial to the EU in total, and not limited to only Sweden.

The investigation by Granlund & Lang (2017) notes that passenger car drivers/owners should be charged reasonably high maintenance costs for freeways. Road width, number of lanes, maintenance standards, etc., are designed for passenger car comfort in traffic up to 120 km/h and frequently using the overtaking (fast) lane/lanes, rather than for HGV´s. The maintenance standard for maximum rut depth in the overtaking lane is less relevant for heavy vehicle combinations at max speed 80 km/h, mainly using the ordinary (slow) lane.

Granlund & Lang (2017) discusses a common and serious error in road damage analysis; stresses and strains under 10 tonnes axle load (50 kN wheel load) on dual mounted tyres are compared with corresponding stress and strain values under wide base tyres carrying the same axle load. Wide base tyres are typically mounted on 8-tonnes axles or 9-tonnes axles, and thus in reality carry 1 - 2 tonnes less axle load than the road damage calculations are erroneously assuming. In fact, only few among all 385 mm standard width wide base tyres are authorized to carry 5 tonnes (50 kN). Those heavy-duty special tyres have advanced reinforcements and are more expensive than regular wide base tyres; hence, they are not used on most HGV:s. At the bottom line, this means that many pavement damage analysis of the difference between the tyre configurations are irrelevant.

Granlund & Lang (2017) used the value 2.19 for the B_{ij} tyre configuration correction factor in the Fourth Power Law calculations. This value is relevant for 365 mm wide base tyres, which is a rather uncommon tyre width. The results for vehicles on single mounted wide tyres presented in this paper are calculated with $B_{ij} = 1.79$, which is relevant for standard 385 mm

wide base tyres. Therefore, this paper shows slightly lower Road Repair Cost for some HGV combinations, compared to figures originally reported by Granlund & Lang (2017).

In Sweden, a long-term trend is increased use of a steerable tag axle on heavy trucks. This trend is currently further strengthened, due to the raise in GCW to 74 tonnes in 2018. Steerable axles have single mounted tyres, while most drive axles have dual mounted tyres. This leads to significantly different vertical loads on the axles within the axle groups on different vehicle combinations on the market but is not taken in to account in analyses in the report by Granlund & Lang (2017).

The European project COST 334 pinpoints that dual mounted wheels provide increased road damage when driving on roads that are already rutted and unevenly deformed (especially at different air pressure in the inner and outer tyres). Furthermore, Swedish law require 5 mm minimum tread depth on the inner dual tyre, while accepting the outer tyre wearing down through all the tread until the tyre's steel belt is visible. This may cause transfer of load between dual mounted tyres. These facts are neglected in most (probably: all) studies of the difference in road damage between dual mounted tyres and wide base tyres. Therefore, many conclusions on road damage from dual narrow base tyres vs single wide base tyres in the international literature may lack validity for Swedish state roads.

5. Conclusion

The main values of roads are not in pavements, but in the benefit of the transports supported by the roads. Pavements shall be properly designed, constructed and maintained to be rideable during a relevant period. In fact, the top pavement layer is named *wearing course*, since it is designed for wear. Hence, focus shall not be on road wear as such, but rather on factors causing premature pavement failure and reducing normal pavement service life. The literature study made by Granlund & Lang (2017) found that errors in pavement designs not relevant for actual climate, bad construction practices and lack of proper maintenance of roads, all together reduce pavement service life more than traffic loads does.

A reference cost for road damage from Heavy Goods Vehicles (HGV´s) was identified from the annual cost for maintenance and repair of state paved roads in Sweden. This cost was split into two costs for repair; one cost for traffic load related damages and one cost non-traffic related damages. The split was made with a ratio 25 % cost for repair of traffic-related damages and 75 % cost for repair of non-traffic related damages. This way, the cost for repair of traffic-related damages was determined to 0.091 Billion € / year. This cost was distributed to the measured traffic work done by HGV:s as well as by the average number of Equivalent Standard Axle Load per HGV. This lead to a reference cost for repair of traffic-related damages of 0.011 €/ESAL$_{10}$*km and 0.014 €/km for the average HGV.

The *Fourth Power Law* in a version modified to consider axle and wheel configurations was used to calculate the road damaging effect of eleven HGV combinations. Finally, the reference cost and the pavement damage factors for the eleven HGV combinations were used to calculate the cost for road damage for each HGV type. Road Repair Cost per payload ton & 100 km (RRC) varies near tenfold, from 0.043 € to 0.36 € between the HGV combinations.

By far the highest RRC is caused by a heavily loaded small two-axle rigid truck and by the 40 tonnes EU semitrailer with two-axle tractor unit. All vehicle combinations with total weight of 44+ tonnes yield moderate RRC, thanks to increased number of axles that distributes the vertical load over the pavement. The lowest Road Repair Cost per payload ton and 100 km is achieved by 74 tonnes high capacity modular vehicles, operating on properly constructed pavements. Vehicle combinations with 60 and 64 tonnes total weight cause as much road damage, or more, on the pavement (per payload ton and 100 km), as 74 tonnes rigs do.

The ratio between governmental accounted cost for repair of road damage caused by heavy vehicles and the Swedish governmental proposed fee for road wear was found to be about 1:8. This showed that the proposed fee is very high, being a tax rather than representing true cost coverage. After the industry reported this finding, the government withdrew their investigation on a fee. Eventually the government has proposed a new concept for road tax on heavy vehicle traffic; see PM '*Fi2018/01103/S2*' from the Swedish Government Department of Treasury.

6. Acknowledgements

7. References

- 'Ändrade bruttoviktstabeller och krav för 64 ton tunga fordonskombinationer'. (2015). Transportstyrelsen.
  Internet 2018-04-30: https://www.transportstyrelsen.se/sv/Nyhetsarkiv/andrade-bruttoviktstabeller-och-krav-for-64-ton-tunga-fordonskombinationer/
- 'Lag om ändring i lagen om vägtrafikdefinitioner', SFS 2017:360.
  Internet 2018-04-30: http://www.notisum.se/rnp/sls/sfs/20170360.pdf
- 'Vägskatt'. (2017). Statens Offentliga Utredningar, SOU 2017:11.
  Internet 2018-04-30: http://www.regeringen.se/rattsdokument/statens-offentliga-utredningar/2017/02/sou-201711/
- Granlund, J. & Lang, J. (2017). 'Förkortad väglivslängd – Orsaker och kostnader'. WSP Sweden AB. Published 2016-05-23, revised 2017-06-28.
  Internet 2018-04-30: https://www.akeri.se/sites/default/files/2018-10/F%C3%B6rkortad%20v%C3%A4glivsl%C3%A4ngd%20-%20Orsaker%20och%20kostnader%2C%20rev%202017-06-28.pdf
- Hjort, M., Haraldsson, M. & Jansen, J.M. (2008). 'Road wear from heavy vehicles'. Nordiskt Vägforum. NVF rapport 08/2008.
  Internet 2018-04-30: http://www.nvfnorden.org/lisalib/getfile.aspx?itemid=261

- 'Lastbilstrafik 2016' ('Swedish national and international road goods transport 2016'. Trafikanalys, Statistik 2017:14. Internet 2018-04-30: https://www.trafa.se/globalassets/statistik/vagtrafik/lastbilstrafik/2016/lastbilstrafik-2016-helar.pdf
- 'Effects of Wide Single Tyres and Dual Tyres'. European Commission Directorate General Transport. COST 334. Internet 2018-04-30: http://www.comt.ca/english/programs/trucking/Pavements/European%20Commission%20COST%20334%20Study%20-%20Effects%20of%20Wide%20Single%20Tyres%20and%20Dual%20Tires%202001.pdf
- Djärf, L., Huhtala, M. Johansson, M. & Samuelsson, E. (1989). 'Optimalt däckval för tunga fordon'. Transportforskningskommissionen, TFK Rapport 1989-5. Internet 2018-04-30: http://www.nvfnorden.org/library/Files/Utskott-och-tema/Fordon-och-transporter/Optimalt%20d%C3%A4ckval%20f%C3%B6r%20tunga%20fordon,%20Rapport%201989-5.pdf
- 'En ny inriktning för beskattning av tung lastbilstrafik'. (2018). The Swedish Government, Department of Treasury, Fi2018/01103/S2. Internet 2018-04-30: http://www.regeringen.se/493c40/contentassets/bb9851db3e3a4b41ba722d6da8eef327/en-ny-inriktning-for-beskattning-av-tung-lastbilstrafik.pdf

International References in the Summarized Report by Granlund & Lang (2017)
- Costanzi, M. & Cebon, D. (2007). 'An investigation of the effects of lorry suspension performance on road maintenance costs'. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 221. pp. 1265-1277. ISSN 0954-4062. Internet 2018-04-30: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.822.6503&rep=rep1&type=pdf
- Cebon, D. (1999). 'Handbook of Vehicle-Road Interaction'. Swets & Zeilinger Publishers.
- 'Dynamic Interaction between Vehicle and Infrastructure Experiment, DIVINE'. (1998). Technical Report, OECD. Internet 2018-04-30: http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/DOT/RTR/IR6(98)1/FINAL&docLanguage=En
- Höbeda, P. (2000). 'Testing the Durability of Asphalt Mixes for Severe Winter Conditions'. Eurasphalt & Eurobitume Congress, Barcelona.
- Jansen, J.M. (2002). 'Særtransporters vejslid – Klassificering av køretøjer'. Vejdirektoratet, rapport 269.
- 'Pavements Lessons Learned from the AASHO Road Test and Performance of the Interstate Highway System'. (2007). Transportation Research Board, TRB Transportation Research Circular E-C 118. Internet 2018-04-30: http://onlinepubs.trb.org/onlinepubs/circulars/ec118.pdf
- Saint-Venant, A.J.C.B. (1855). 'Mémoire sur la Torsion des Prismes'. Mem. Divers Savants, 14.
- 'The AASHO Road Test. Report 5: Pavement Research'. (1962). Highway Research Board. Special Report 61E. Washington D.C.
- Varin, P., Matintupa, A., Saarenketo, T. & Granlund, J. (2012). 'Impact Analysis of Kaunisvaara – Svappavaara Road Iron Ore Transportation Options'. International Heavy Vehicle Transport Technology Symposia, HVTT12. Internet 2018-04-30: http://road-transport-technology.org/Proceedings/HVTT%2012/Impact%20Analysis%20of%20Kaunisvaara%20.%20Svappavaara%20Road%20Iron%20Ore%20Transportation%20Options%20-%20Varin.pdf
- Varin, P. & Saarenketo, T. (2014). 'Effect of axle and tyre configurations on pavement durability – A prestudy'. The ROADEX Network. Internet 2018-04-30: http://www.roadex.org/wp-content/uploads/2014/10/ROADEX_Axle_Tyre_Prestudy_15102014%20Final.pdf