Characterization of Heavy Traffic on the Swedish Road Network

S. Erlingsson
Highway Engineering, VTI – The Swedish National Road and Transport Research Institute, Linköping, Sweden
&
Faculty of Civil and Environmental Engineering, University of Iceland, Reykjavik, Iceland

ABSTRACT: One of the key parameters in predicting the deterioration process of pavement structures is linked to the heavy traffic characteristics. The heavy traffic loading has been commonly expressed in pavement design methods through an equivalent number of repetitions of standard axle loads (ESAL's). Recent pavement distress models, used in new mechanistic pavement design methods, require more detailed description of the heavy traffic. In Sweden, a Bridge Weigh-In-Motion (BWIM) system has been used to collect information about the heavy traffic on the road network. The system provides information about the vehicles' time of passing, speed and lane, the number of axles and their configurations and weights. A national BWIM network was established in 2004, consisting of twelve locations which are measured during one week every year. The network consists of motorways, arterials or trunk roads as well as one county road. This, therefore, provides a basis to establish an Axle Load Spectra (ALS) which gives the load distribution of steering axles, other single axles, tandem and tridem axles. As very few quad axles are registered they have been neglected.

KEY WORDS: Axle loads, weigh-in-motion, pavement performance, axle load spectra.

1 INTRODUCTION

Pavements deteriorate due to heavy traffic loading and the environment. One of the key parameters in predicting the deterioration process is linked to the heavy traffic characteristics. The heavy traffic loading has been frequently expressed in pavement design methods through an Equivalent number of repetitions of Standard Axle Loads (ESAL's). New pavement performance models used in mechanistic – empirical (M-E) pavement design methods require more detailed information regarding the traffic characteristics than in previous empirical methods where traffic data has usually been aggregated into ESAL's (Lu and Harvey, 2006). Weigh-In-Motion (WIM) systems measure continuously and store axle loads and axle spacing data for each vehicle as well as time of passing, speed and lane direction. Based on the data restored, the vehicles can be categorized into vehicle groups. Further can the information be used to construct Axle Load Spectra's (ALS). ALS spectra presents the load distribution of the vehicle axle groups during a period of time.

In Sweden, a Bridge Weigh-In-Motion (BWIM) system has been used to collect information about the heavy traffic on the road network (Winnerholt and Persson, 2010). The system provides information about the vehicles' time of passing, speed and lane, the number of axles and their configurations and weights. A national BWIM network was established in

2004, consisting of twelve locations which are measured during one week every year. The network consists of motorways, arterials or trunk roads as well as one county road. This therefore provides a basis to establish an Axle Load Spectra (ALS) which gives the load distribution of steering axles, other single axles, tandem and tridems axles. As very few quad axles are registered they have been neglected. The load distribution throughout the day is also gathered.

Even though WIM-systems gives quite detailed information about the traffic characteristics, there are still important parameters for pavements deterioration development that are not provided such as lateral wander distribution characteristics of the heavy traffic, tyre pressures and single versus dual tyre configuration of the individual axles.

The objective of this paper is to provide information about the current axle loads from the heavy traffic in Sweden, in terms of composition and volume. This is done by expressing the data as ALS.

2 THE SWEDISH BWIM SYSTEM

The Swedish BWIM is a mobile system mounted on concrete bridges (The Swedish Road Administration, 2004 and 2006). The system consists of extensometers (strain gauges) and a data logger, see Figure 1. Two sets of strain gauges are attached to the bottom surface of a bridge slab (Znidaric et al., 2005). Two pairs of extensometers works as axle detectors and as a vehicle passes over the bridge they register the time and speed of the vehicle along with the vehicle axle configuration (number of axles, their type as well as the distance between the axles). The strain induced by the different vehicle axles are detected by a row of extensometers and gives their axle loads. All information is thereafter stored in the data logger. Depending on the bridge width eight or twelve extensometers are used for weighing the axle. The system is calibrated to give correct axle load values (Erlingsson et al., 2010).

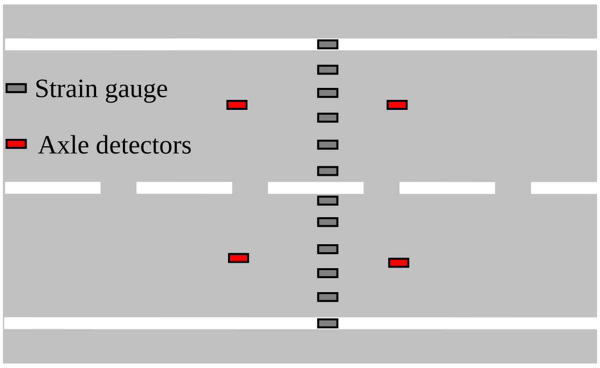

Figure 1: The BWIM system used in Sweden consist of two sets of extensometers. One set (four sensors) for detecting the axles and the other set (eight or twelve strain gauges) for weighing the axles.

The contribution from light traffic (automobiles) is considerable in volume but has very limited effect for the deterioration process so they have been sorted out of the data sets. Thus only vehicles with total weight > 35 kN (3.5 ton) are registered. Further, the system is programmed so that two or more suggestive axles are considered to belong to the same axle group if their reciprocal distances are less than 1.8 m.

3 THE NATIONAL SITES

The national sites in Sweden consist of twelve locations which are monitored during one week every year. The sites cover geographically the whole country, however with more concentration in the southern part as most of the traffic is there. Eight of the twelve sites are motorways; three are arterial or trucks roads and one is a county road. Figure 2 show the geographical location of the measurement stations and Table 1 provides a short overview of the measurements carried out in year 2007.

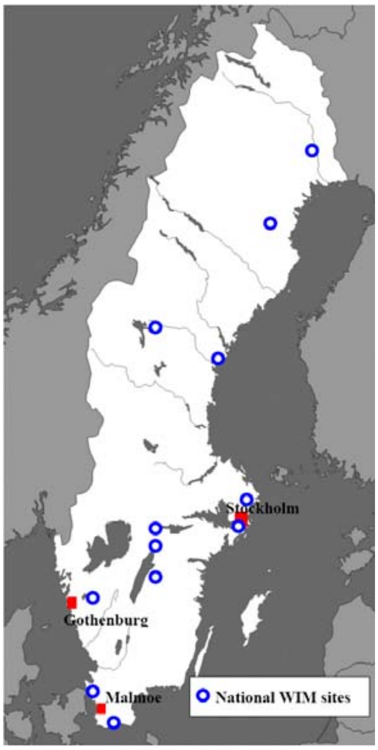

Figure 3: Location of the National BWIM sites in Sweden.

Table 1: Overview of the measurements carried out in the National BWIM system during the year 2007. M is motorway, A is arterial and C is a county road. 1+1 stands for one lane in each direction and 2 is two lanes in the same direction.

Road type	Station no.	Station name	No. of lanes	Time period	No. of vehicles	No. of axle groups
M	E4	Torsboda	1 + 1	2007-08-01 - 2007-08-07	7150	22655
M	E4	Mjölby N	2	2007-04-13 - 2007-04-20	10756	38341
M	E6	Löddeköping	2	2007-05-09 - 2007-05-15	15436	49325
M	E10	Grundträskån	1 +1	2007-08-23 - 2007-08-30	1309	4643
M	E14	Torvalla	1 + 1	2007-08-03 - 2007-08-09	2120	6590
M	E18	Radmansö	1 +1	2007-06-21 - 2007-06-27	3739	12786
M	E20	Marieberg	2	2007-04-12 - 2007-04-19	10505	37808
M	E65	Skurup	1 + 1	2007-05-23 - 2007-05-29	6061	18980
A	Rv40	Landvetter E	2	2007-05-24 - 2007-0530	7645	24878
A	Rv50	Gärdshyttan	1 + 1	2007-10-09 - 2007-10-18	6703	24692
A	Rv73	Västerhaninge	2	2007-09-26 - 2007-10-02	3165	7630
C	Lv373	Storlångträsk	1 + 1	2007-08-21 - 2007-08-24	481	1836

4 AXLE LOAD DISTRIBUTION

The analysis of the BWIM data is straight forward. The data are gathered together into axle configuration groups giving the steering, single, tandem and tridem axles. As the number of quad axles is very limited (usually less than 5 during one week measuring time) they have been neglected. The data is thereafter represented in histograms, here using a bin width of 10 kN (1.0 ton).

Figure 3 shows the ALS for the site Marieberg on the Motorway E20. The frequency of the spectra is normalized to represent the normalized amount of each axle load type.

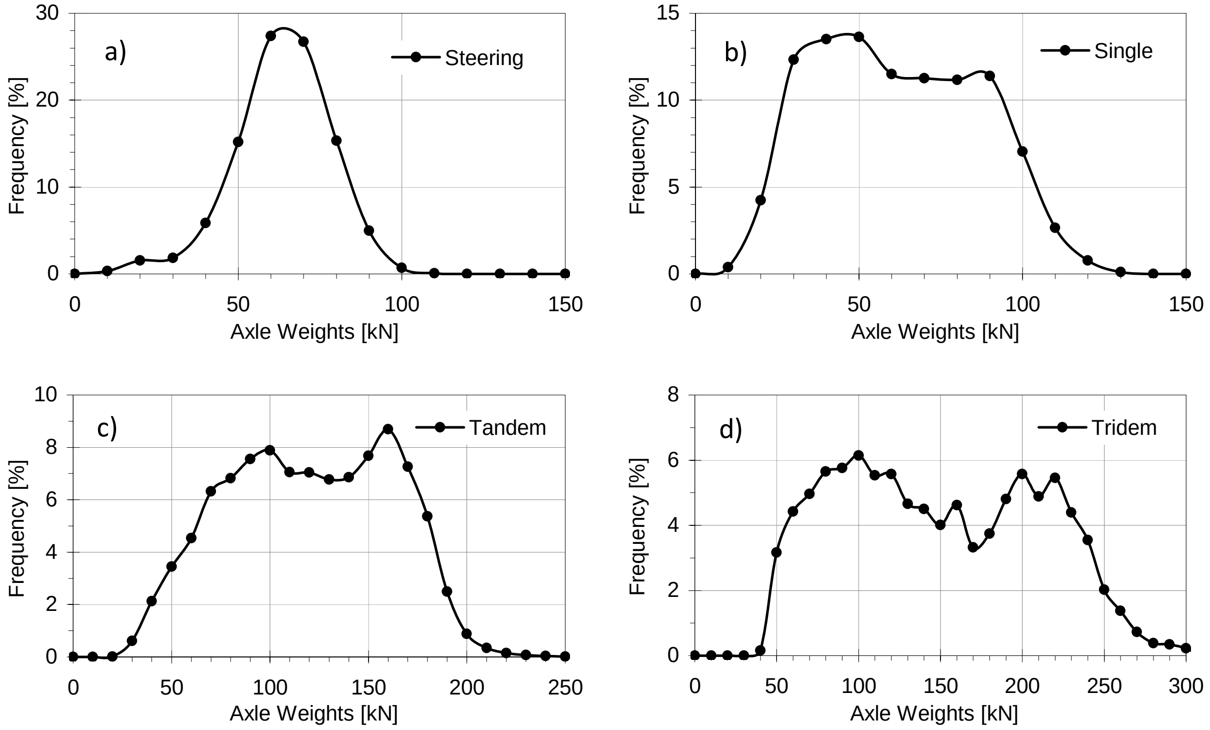

Figure 3: Axle load spectra at the national site Marieberg (E20). a) steering axles, b) single axles, c) tandem axles and d) tridem axles.

As can been seen in Figure 3 the weight of the steering axles are quite normally distributed and lies mostly within the range 30 – 100 kN with an average value of 66 kN and a standard deviation of 14.7 kN. The spectra's for the other axle types are much broader. The single axles lie within the range 10 – 120 kN and are quite evenly distributed within the range 30 – 80 kN. The tandem axles are within the range 30 – 210 kN, but lie manly within 70 – 170 kN range. The tridem axles are then within the range 40 – 290 kN but manly within 50 – 230 kN.

The data has been analysed in order to create a representative ALS for the sites. A simple summary of the data is given in Table 3, where a normalized quantification of the different axle types is given. The column Axle/vehicle gives the ratio between the total number of axle groups registered normalized with the total number of vehicles (steering axles). This, therefore, represents the average number of axle groups per vehicle. The three remaining columns represent the number of single, tandem and tridem axle groups normalized with the number of steering axles.

Table 3: Axle Load Spectra characteristics for the national sites measured during one week in 2007.

Station No.	Name	No. of vehicles	Axle/vehicle	Single/steering	Tand/steering	Tri/steering
E4	Torsboda	7150	3.17	0.89	1.19	0.09
E4	Mjölby N	10756	3.56	1.19	0.96	0.41
E6	Löddeköping	15436	3.20	1.19	0.62	0.39
E10	Grundträskån	1309	3.55	1.16	1.23	0.15
E14	Torvalla	2120	3.11	1.11	0.94	0.06
E18	Radmansö	3739	3.42	1.23	0.76	0.42
E20	Marieberg	10505	3.60	1.22	1.13	0.25
E65	Skurup	6061	3.13	1.25	0.62	0.27
Rv40	Landvetter E	7645	3.25	1.12	0.83	0.30
Rv50	Gärdshyttan	6703	3.68	1.42	1.01	0.25
Rv73	Västerhaninge	3165	2.41	1.02	0.35	0.04
Lv373	Storlångträsk	481	3.82	1.03	1.67	0.11
		Average	3.33	1.15	0.94	0.23
		St. dev.	0.37	0.13	0.35	0.14

As can be seen in Table 3 the ratio number of axle groups per vehicle over the number of vehicle (Axle/vehicle) is quite constant for all the sites, and lies within the range 3.11 and 3.82 except for one station (Västerhaninge) where the value is 2.41. Further, it is interesting to see the normalized contribution of each axle. It can be seen that in average, a 1.15 single axles (besides the steering axle) belong to each heavy vehicle, 0.94 tandem axles and 0.23 tridem axles. All this indicates that the composition of the heavy vehicle fleet show similarities to some extent between the different sites although considerable variations occur. No general ALS can therefore be given that is valid for all the national sites on the Swedish network.

Two stations have been analysed to estimate how the axle load spectra is changing over time. Table 2 shows the time period where data was gathered and Figure 4 shows the results for the motorway E4 Mjölby for the five years 2004 – 2008.

Table 2: Sampling period behind the Axle Load Spectra for the years 2004 – 2008 for the 2 lane motorway E4 Mjölby N (northbound direction).

Time period	Week no.	No. of vehicles	No. of axle groups
2004-04-01 - 2004-04-07	14 - 15	9106	31922
2005-04-12 – 2005-04-18	15 - 16	9157	33471
2006-04-19 – 2006-04-25	16 - 17	9831	35860
2007-04-13 – 2007-04-19	15 - 16	10756	38341
2008-04-10 – 2008-04-16	15 - 16	10185	36783

As can be seen in Figure 4 the general shape of the ALS does not change much with time. However variations occur. Looking at Figure 4a) one might think that the steering axles are getting lighter as the peak of the spectra is shifted to the left with time. One needs however to bear in mind that the Swedish BWIM system is a mobile system where only data is gathered during one week per year, although it is usually the same week during the year, in this case early April. For the single, tandem and tridem axle groups’ quite similar shape are seen. For further conclusions longer time series are needed.

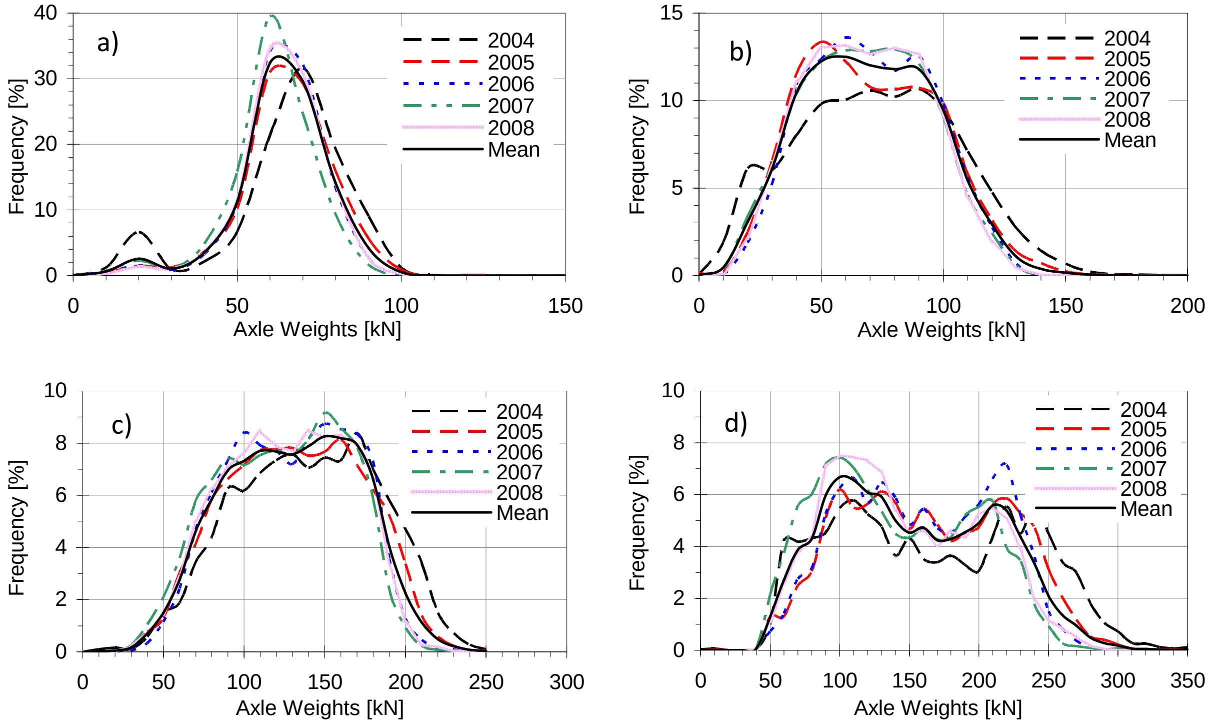

Figure 4: Axle load spectra at the national site Mjölby (E4), northbound direction, for the time period 2004 – 2008. a) steering axles, b) single axles, c) tandem axles and d) tridem axles.

Figure 5 gives now the ALS for the arterial Rv40 Landvätter for the five years period 2004 – 2008.

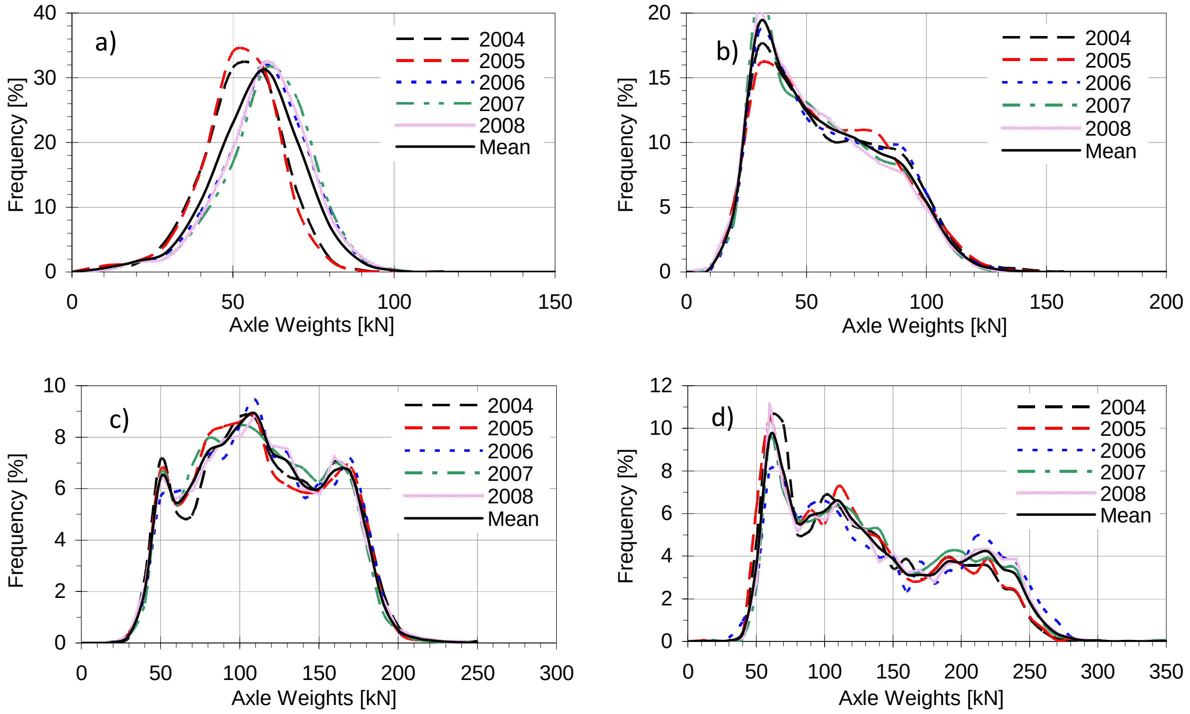

Figure 5: Axle load spectra at the national site Landvätter (Rv40), eastbound direction, for the time period 2004 – 2008. a) steering axles, b) single axles, c) tandem axles and d) tridem axles.

From Figure 5 it can been seen that the spectra is not changing much between the years although some variation occur. By comparing the spectra’s from Figure 5 with the one from Figure 4 it can be stated that they are quite different.

From Figure 4 and 5 it is clear that only moderate differences occurs between the spectra’s based on the individual years. The largest deviation is for the tridem axles as they are approximately only 25% as frequent as the other types. The conclusion is therefore that sampling data for one week are sufficient to build quite reliable axle load spectra for the locations with heavier traffic but for some of the minor roads a longer sampling period is needed to improve the reliability of the ALS.

Based on the ALS data the truck factor T_f (average load equivalency factor of each heavy vehicle) can now be estimated, using the forth power law, as

$$T_f = \frac{1}{N_{hv}} \cdot \sum_{i=1}^{4} N_i \cdot \sum_{j=1}^{n_j} \left(\frac{W_{ij}}{W_{i_{stand}}} \right)^4 \cdot \frac{f_j^{norm}}{100} \tag{1}$$

where N_{hv} is total number of heavy vehicles during the measuring period, W_{ij} is the axle load weight of axle i, j where i represent the different axle categories; steering, single, tandem and tridem, j represent the different axle weight, N_i is the number of axles in each category, f_i^{norm} is the normalized frequency (%) of each axle weight and $W_{i_{stand}}$ is the weight of the respective standard axle category, thus steering (100 kN), single (100 kN), tandem (180 kN) and tridem (240 kN) respectively. The truck factor of all the sites is given in Figure 6.

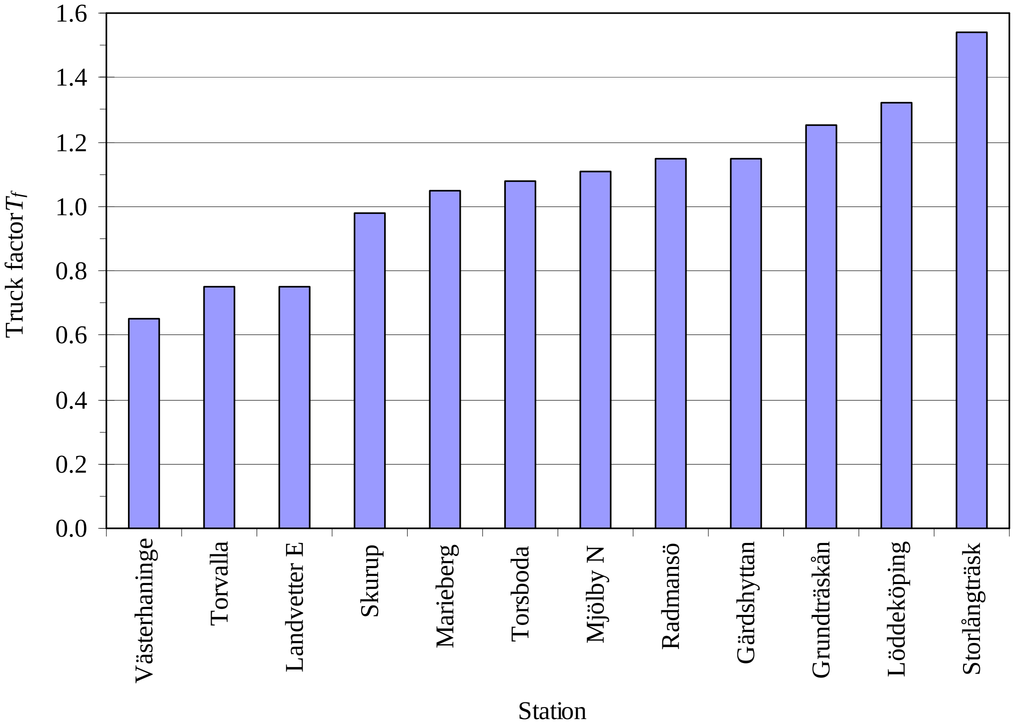

Figure 6: The truck factor for all the twelve BWIM stations arrangest from the lowest to the highest.

From Figure 6 it can been seen that the truck factor varies from 0.65 to 1.54. This broad variation has a great impact on the performance.

5 CONCLUSIONS

Heavy traffic characteristics, based on BWIM data from the Swedish national sites have been analysed and presented as ALS distributions. Some of the main findings can be summarized as follows:

- Considerable variations occur between the ALS from different sites. No general ALS can therefore be given that is valid for all the national sites on the Swedish network.
- Truck factor based on the ALS indicate that the load of axles at the different sites is very site depended.
- Sampling data for one week are sufficient to build reliable axle load spectra for the locations with heavier traffic. This is true for the steering, single and tandem axles. As tridem axles are approximately only 25% as frequent as the other axle types, longer sampling periods would probably improve the spectra. For some of the arterials or truck roads and the county road a longer sampling period is needed to improve the quality of the ALS for all axle types.

As has been previously stated the axle load spectra given here are based on a one week sampling period at each site per year. A longer sampling period would probably improve the data leading to more accurate results. However, as measurements are made yearly it should be possible in the future to build up ALS at each site based on accumulated data from a number of consecutive years. This might improve the prediction of the average ALS for the network but changes in the fleet’s traffic characteristics between years might affect such results.

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