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Undertittel
The ATK/WIM project

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Sammendrag
Trafikkmengde og vekt for kjøretøyene er viktig informasjon for både planlegging, drift og vedlikehold av veger. I Norge finnes det ca. 250 Automatisk Trafikk Kontroll systemer (ATK) som registrerer hastigheten til de passerende kjøretøyene, og som i tillegg kan måle aksellast og akselavstand. Denne rapporten beskriver utviklingen av en metode for å beregne vektdata for tunge kjøretøy fra ATK. Vekten av den første akselen til en seksakslet semitrailer benyttes til å kalibrere vektmålin-gene for hvert enkelt målepunkt (system). Resultatene viser at ATK-systemet kan brukes til å samle statistisk informasjon om vektforde-lingen av tunge kjøretøyer, men det må jobbes videre med nøyaktigheten til målingene.

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Summary
Automatically generated information about traffic volumes and vehicle weight data is highly welcomed in the field of traffic engineering. In Norway, around 250 automatic piezoelectric traffic speed enforcement systems are mounted. Besides the velocities of the passing vehicles, the systems also may detect their axle weights and the axle distances. This report describes the methods developed for evaluating the data quality for the generated weight data. The report introduces the weight of the first axle of a six axle semitrailer vehicle as a weight data quality indicator and sets the first steps towards a calibration method. The results show that the speed enforcement system could be used for gathering statistical information about the weight distribution of heavy vehicles.

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Determination of vehicle weight data from speed enforcement systems in Norway - The ATK/WIM project

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Preface

This report is the result of a research cooperation between the Traffic Engineering Research Centre at the Norwegian university of science and technology NTNU and the Norwegian public roads administration (NPRA).

There has been an interest in reliable axle and vehicle weight data within the NPRA for many years. Different previous projects were dealing with the accuracy and reliability of weight data from commercial weigh in motion (WIM) systems. This research project started in spring 2016 with Timothy Pedersen's master thesis, were he first evaluated the usability of weight data from the Norwegian speed enforcement system ATK. The promising results of that work motivated the NPRA to further investigate the topic. During the summer 2016, the project became a part of the NPRA innovation program which provided further funding for additional work. The years 2016 and 2017 were used to test the usability and accuracy of weight data from the ATK units. The entire project was throughout all its phases a close cooperation between the NTNU and different groups within the NPRA.

Intermediate results were discussed and presented at different national and international forums and conferences. Four scientific papers where published during the project and are listed at the end of the document. This report gives an overview over the conducted work and summarizes all important results which were produced until January 2019.

Future systems for design and evaluation of pavements are fully dependent on reliable traffic data with good knowledge about the amount and weight of all categories of vehicles. NPRA started in 2018 the R&D-programme VegDim (2018-2022), where the goal is to develop a new analytical pavement design system. Here, traffic data will be a central input parameter. The completion of this report is therefore financed by the VegDim programme.

Summary

Vehicle weight data is an important topic within the field of traffic engineering. Especially automatically generated information about traffic volumes, speed levels and the weight of vehicles is highly welcomed. In Norway, around 250 automatic piezoelectric traffic speed enforcement systems are mounted all over the country. The used piezoelectric cables are low cost devices, which are sensitive to pressure and mounted in a depth of ca. 30mm in the pavement. Besides the velocities of the passing vehicles, the systems also detect their axle weights and the axle distances. However, the quality and usability of the weight data from speed enforcement systems has been unknown and the data has not been utilized. This report will describe the methods developed for evaluating the data quality for the generated weight data. Performed field tests helped to understand the systems performance and were evaluated with respect to the WIM-accuracy standards. The report introduces the weight of the first axle of a six axle semi-trailer vehicle as a weight data quality indicator and sets the first steps towards a calibration method. The results show that the Norwegian speed enforcement system could indeed be used for gathering statistical information about the weight distribution of heavy vehicles on many roads in Norway.

Keywords: Weigh in motion, ITS, Weight distribution statistic

1. Introduction

The Norwegian Public Roads Administration (NPRA) needs reliable vehicle- and axle-weight data. Information about the number and weight of heavy vehicles can be used for predicting road wear and for optimizing asphalt structures as well as for statistical analyses of vehicle weights. A common approach for collecting the weight of vehicles is to measure their static weight at a roadside weigh station. These measurements are highly accurate but the procedure of stopping the vehicles and checking their static weight at a weigh station is often limited by their capacity [1].

Automatic weighing systems, which are capable of measuring the weight of moving vehicles, are a promising approach for the collection of weight data. Weigh in motion (WIM) systems are measuring the weight of an axle while it is driving over a sensor by registering the created dynamic forces [2] [3]. The static weight for each passing axle is estimated out of these signals. A common type of WIM sensors are piezoelectric cables. Piezoelectric cables are pressure sensitive devices and mounted in the top layer of the asphalt. Compared to other WIM installations, piezoelectric cables are relatively easy to install and less expensive [4].

While in many other countries radar systems are used for speed enforcement purposes, the Norwegian Public Roads Administration is operating an automatic speed enforcement system based on piezoelectric cables, called ‘automatisk trafikkontroll’ (ATK). Around 250 ATK units are installed all over the country. Each of the sites consists of two piezoelectric cables, a camera unit and a data logger. The used cables are piezoceramic cables and classified as class I accuracy by the manufacturer. The data logging unit is calculating the speed of the passing vehicles, by measuring the time for each axle of a vehicle to pass the distance of three meters between the two cables. In case a passing vehicle is speeding, a photo is taken by the camera and a speeding ticket will be sent to the driver. Figure 1 shows two piezo cables, installed at a depth of 25 mm in the asphalt top layer and the corresponding camera unit. Besides the velocities of the passing vehicles, the piezoelectric cables are also measuring the weight of the passing axles and the distances in-between. Since the data loggers are not optimized for weight data collection, the quality and usability of the weight data from ATK systems has been unknown. The data has not been further tested or utilized. Weight data thus became an unused by product from the ATK units.

Weight data is a desirable source of information for many fields in road and traffic engineering one of the most frequently used fields of application are:

- Pavement design and maintenance
- Bridge design
- Size and weight enforcement
- Administration and planning

Figure 1 ATK Piezo cables and camera unit

The Norwegian public roads administration started this project to evaluate, whether this data could be used for gaining statistical information about the weight distribution of heavy vehicles on the Norwegian road network. That information could be particularly useful for road and pavement design. The entire project was a close cooperation between the NPRA traffic data and pavement group. Since the used piezo cables are not suitable for accurate measurement of overloads or a narrow range of heavy loads [5], the aim of this project was to use the ATK system for the monitoring of average truck loads and weight distributions on the Norwegian road network.

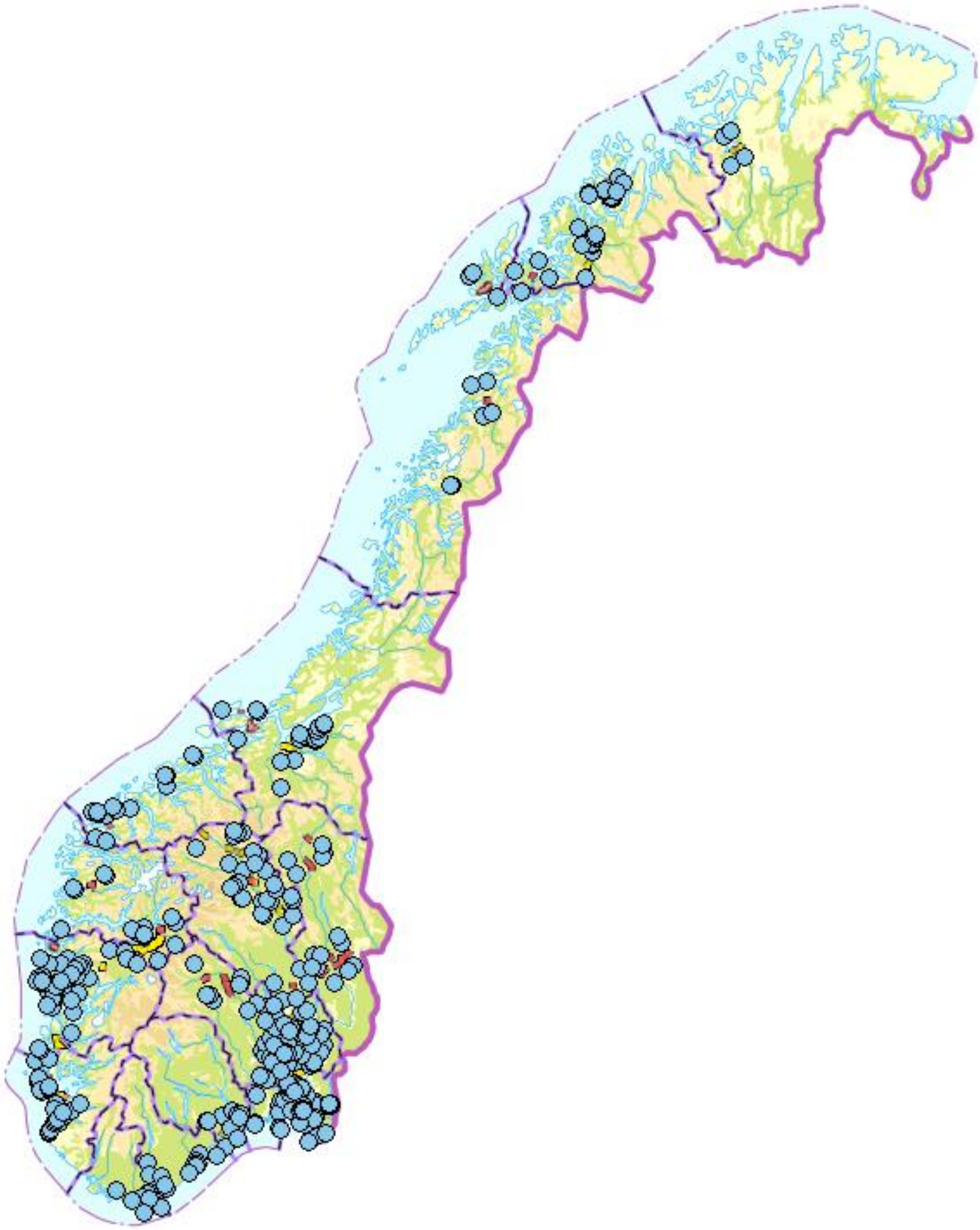

Figure 2 Overview over ATK sensors in Norway

Figure 2 gives an overview over all ATK sensors and their location in Norway.

2. WIM & ATK systems in Norway

Weigh in motion technology has been the subject of different research approaches within the NPRA throughout the last years. Different types of sensors were installed on roads and tested in previous projects. Traditional weigh in motion units consist of a load sensor, installed in the road and a roadside data logger, which is processing the signals. The two types of load sensors used and tested in Norway are:

- piezoelectric sensors
  - piezoceramic sensors
  - piezo polymer sensors
- lines quartz sensors

Piezoelectric sensors are available in to different types, piezoceramic and piezo polymer sensors and can have both a flat or a round from. The Norwegian ATK systems is using flat piezo polymer cables as load sensor. Some few old ATK units do also still use round cables, but these are about to be changed to flat ones all over the country. A piezoelectric cable is a pressure sensitive device which generates an electrical voltage when its deformed. A tire, driving over the cable is causing such a deformation and thus an electrical voltage is generated. The voltage increases with higher deformations, caused for example by heavier vehicles [6]. A lineas quarts sensor is based on quartz elements which yield an electrical signal proportional to the applied force.

The dynamic load signals from piezoelectric cables can be affected by the asphalt temperature [6]. Hence, these WIM systems need a device for adjusting the registered signals related to the actual local temperature. Many commercial WIM systems based on piezo cables include a temperature sensor installed in the asphalt [6]. The Norwegian ATK units do not have such temperature sensors, since the units are optimized for speed enforcement. Neither does the software from the data logger adjust the weight signals with respect to the current temperature. This work developed a post processing temperature calibration method, using free weather data from the Norwegian meteorological institute.

Several research approaches evaluated the accuracy of different WIM systems in many countries throughout the last years. The NPRA is using two piezoelectric based WIM systems and the lineas quartz sensors from the manufacturer Kistler. Previous research showed that all piezo-based systems are vulnerable to over- and underestimation of the actual static vehicle weight. A commercial piezo-based WIM system underestimated the static vehicle weight with up to 25%. Additionally, a variation of the accuracy of the systems over certain periods was documented [1]. Especially piezoelectric WIM systems varied significantly in their accuracy over a period of a few months. Calibration factors helped to improve the data quality of the WIM systems in these studies. Previous examinations indicated for all piezoelectric based WIM systems in Norway systematic errors.

The previously mentioned research approaches indicate that data from piezoelectric sensors is often lacking a desired level of accuracy. The fact that these commercial piezoelectric WIM systems were hardly able to provide accurate and reliable data over a longer period motivated the NPRA to investigate the possible usability of weight data from ATK sensors for WIM purposes. As mentioned, these ATK systems do also use piezoelectric cables, but are in general not optimized for weight data collection. The high amount of 250 available sensors offers a good source of vehicle weight data across the entire country. Each ATK point could potentially provide the NPRA with WIM data at negligible cost. This project has a high potential benefit, since all the roadside infrastructure already exist.

3. Methodology

This project evaluates the quality of WIM data from ATK units in a two-step approach. First, the static weights from a close-by weigh station are compared to the dynamic weights measured with the ATK system. The ATK unit is categorized into an accuracy class, following the categorization from the COST 323 report. Second, a post processing data calibration method is developed to examine a possible increase in the accuracy of the data.

3.1 Quality assessment

A common method to evaluate the quality and accuracy of WIM data are field tests. During these tests, static and dynamic vehicle weights are compared to each other. These tests could either be done by checking the weight of trucks from the free flow traffic or by using pre-weighted vehicles. Such tests were also performed in Norway and indicate the performance of the examined ATK system for the day of the particular test.

The collected static weights from local weigh stations can be assumed as very accurate and close to the actual weight of the vehicle. The weight sensors of these local weight stations are calibrated frequently, since they are used for the enforcement of weight limits. The static axle weights of vehicles were registered and compared to the corresponding dynamic ATK weight data during several field tests. These tests were performed in different parts of Norway at static weigh stations, with nearby ATK sites. During a field test different types of heavy vehicles from the free-flowing traffic were stopped. Their static axle weights were measured and afterwards matched to the related weight data from the close by ATK units. The detailed matching of the vehicles was done with the help of videos from both the static weight stations and the ATK unit.

3.2 COST 323 WIM data accuracy standard

The project evaluated the field tests with respect to the European WIM standard, defined and implemented by the COST 323 report. The COST 323 report defines several accuracy classes (AC) for weight-in-motion data. Each AC is labelled with a letter from A to E, where A equals the best accuracy class and E the lowest. Each letter is followed by the tolerance of the relevant confidence interval (e.g. 10%) in percent. The standard deviation of a data series describes the width of such a confidence interval. Table 1 gives an overview of the accuracy classes and the given tolerances. A unit can be categorized within one of these classes if the standard deviation of the data is within the given range.

Table 1 COST 323 accuracy classes (AC) and tolerances (T) in %

AC	A	B+	B	C	D+	D	E
T [%]	5	7	10	15	20	25	>25

The COST 323 report also defines a range of applications for each accuracy class. The highest classes (A and B+) can be used for the enforcement of legal weight limits. The accuracy classes B and C are sufficient to investigate the fatigue and wear of asphalt as well as for design and maintenance of roads and bridges or for a pre-selection of potentially overloaded vehicles. The classes C to D can be used for utilizing weight data for statistical purposes in economical and technical studies. Since the main focus of this report is the statistical evaluation of weight data, a high accuracy class, such as A or B+ is not necessarily needed for this field of application [7].

3.3 Data quality indicator

For this project an additional quality indicator, which describes the weight data quality of an ATK site without performing a field test, is highly welcomed. A characteristic vehicle class (CVC) could fulfil that demand by delivering comparable weight data of a specific vehicle type. In most countries and road networks, a group of characteristic vehicles can be identified. A group of characteristic vehicles consists of similar vehicles with a low variation and a constant mean gross- or axle weight [8]. The chosen group of characteristic vehicles in this project are six axle semi-trailer vehicles. Figure 3 shows a drawing of a vehicle from the CVC.

Figure 3 Exemplary six axle semitrailer vehicle from characteristic vehicle group (CVC)

These vehicles are common in Norway and have a legal weight limit of 50 tons. Previous research, done by van Loo and Lees in 2015 on quality indicators for WIM systems showed, that especially the weight of the first axle of vehicles in this group is very stable in a range between 6.5 and 7 tons. A long-time field test with a Kistler lineas quarts WIM senor along E6 in Verdal (Trøndelag) proofed the applicability of these values on the Norwegian road network. Table 2 shows the result of that field study.

Table 2 Results Kistler Verdal 2016

	Mean (t)	STD (t)	N
Kistler Verdal E6 6ax semi	6.944768	0.866792	36 454

During the long run field study, the weight of the first axle of 76 599 six axle trucks was studied throughout the year 2016. Among these were 36 454 vehicles from the CVC. The average weight for the first axle for both vehicle classes is within the range recommended by van Loo and Lee. The fact that the first axle weights for these vehicles lies on the upper end of the recommended range can be explained by the higher gross weight of these trucks in Norway. The maximum gross weight for the same vehicles is in many western European countries (Germany, France, Austria) between 40 and 44 tons while its 50 tons in Norway.

The first axle of a semi-trailer vehicle seems to have a lower variation in its weight compared to the other axles, since it is less affected by the load on the trailer. The calibration method in this project is thus based on the assumption of a relative stable interval for the weight of the first axle of a six-axle semi-trailer vehicle within a recommended range of 6.5 to 7 tons. According to the previous field study in Verdal, the critical value for the Norwegian case was therefore set to 7.0 tons as a reference. All further analytics use the value for the first axle of the CVC of 7.0 tons. These findings where used as an input for the further calibration method and applied in the data calibration method which is introduced in the following part.

3.4 ATK data calibration factor

The findings, presented in the previous chapter motivated us to test a calibration method for the ATK units, based on the weight of the first axle of six axle semi-trailer vehicles (CVC). The actual measured average weight for a first axle of a six axle semi-trailer vehicle could be used as a quality indicator and as a baseline for the further calibration. In one of the performed field tests, the sensors are measuring an average weight for the reference axle of 5.47 tons (W_d) while we assume that this value should be 7.0 tons (W_s). For the further calibration method, we assume an ideal weight of this axle of 7.0 tons. Equitation 1 shows the developed calibration factor for the ATK units, using the mean value of the first axle of a six-axle semi-trailer vehicle from a local ATK unit (W_d) and the ideal value of 7.0 tons (W_s).

$$C_{ATK} = 1 + \left(\frac{(W_s - W_d)}{W_s}\right) \qquad \text{(Equiation 1)}$$

The calibration factor C_{ATK} is used for calibrating the entire raw data set of an ATK unit. Therefore, all raw axle weights are multiplied with C_{ATK}. The developed calibration method was applied to the collected dynamic weights of numerous field tests, performed throughout spring 2017.

3.5 Quality assessment

The study indicated that, the weight of the first axle within the CVC could also be used as a data quality indicator for weight data from ATK systems. Numerous field tests proofed that the weight of the first axle of the CVC should be within a range of 5.0 to 9.5 tons with a standard deviation of not more that 25%. Field tests showed that ATK stations with poor data quality had also low first axle weights with a high standard deviation. The introduced quality indicator can so be good way to get a first overview about the data quality of an ATK station without performing a field test.

The main results of the quality assessment part of the project can be summarized as:

- The weight of the first axle of a vehicle from the CVC should be within a range of 5.0 to 9.0 tons
- The standard deviation of the weight of that axle should not be bigger than 25%

- If these conditions are met - the developed calibration method can be applied for calibrating the raw data set

Results and practical examples of these calibration approaches are presented in the results section of this report.

4. ATK data analyses and calibration

The data analyses and calibration section are divided into three parts:

Part I (4.1)

- overview over performed field tests during the project
- evaluation of field test data from different ATK stations all over Norway
- previously introduced calibration method is applied to the data set
- accuracy of the calibration method is discussed

Part II (4.2)

- Presentation of post calibrated ATK data sets to evaluate the weight distribution of heavy vehicles on different road segments in Norway

Part III (4.3)

- Evaluation of the stability of weight data over longer time periods to study potential impacts or variations on the dataset over time

4.1 Field tests

Field tests conducted during the project helped to compare data from ATK units with static weight data from close by weight stations. The static weight of each axle was therefore compared to the equivalent ATK axle weight. These field tests were conducted at different weight station all over the country. Table 3 gives an overview over all conducted field test during the main ATK project. Not all of the listed ATK units were delivering results during the field tests (e.g. due to technical problems with the ATK unit on the particular day). Additional field tests with ATK units were performed during the master thesis project of Timothy Pedersen in 2016. The Kistler lineas quarts sensors, which were often used as a reference data sets during the project where two times calibrated by the project team.

Table 3 Overview performed field tests

Weight station	Region	ATK stations	Date
Stavanger	Rogaland	4	April 2017
Østerholtheia	Aust-Agder	8	April 2017
Åsen	Trøndelag	8	May 2017
Tromsø	Troms	3	May 2017
Otta	Oppland	6	May2017
Tromsø	Troms	4	June 2018

Figure 4 shows a truck which is stopped for checking its weight at the Åsen weight station in Trøndelag along E6.

Figure 4 Field test during a weight control for heavy vehicles at Åsen control station along E6 in Trøndelag

Figure 5 gives an overview over four different field tests, all conducted in spring 2017 (Auråen E18, Gjerdemyra E18, Teikamptunnel E6, Otta E6). Weight data from 74 to 92 heavy vehicles from the free flow traffic was collected. The static weights were measured at local weight stations and the corresponding dynamic weights were measured at a close by ATK point.

The measured dynamic gross weights (GW) are plotted against the static weights as red triangles in Figure 5. A linear regression line (LRL) has been fitted to the data. The additional black y = x line would be the outcome of a 100% accurate WIM system, where every dynamic weight is equal to the static weight. All evaluated ATK points show similar characteristics. Most measured dynamic vehicle weights are underneath the black y=x line and are thus underestimating the static vehicle weights. The error between the static and the dynamic weight is increasing with increasing static weights. These results are in line with previously reported results on WIM systems and ATK units in Norway.

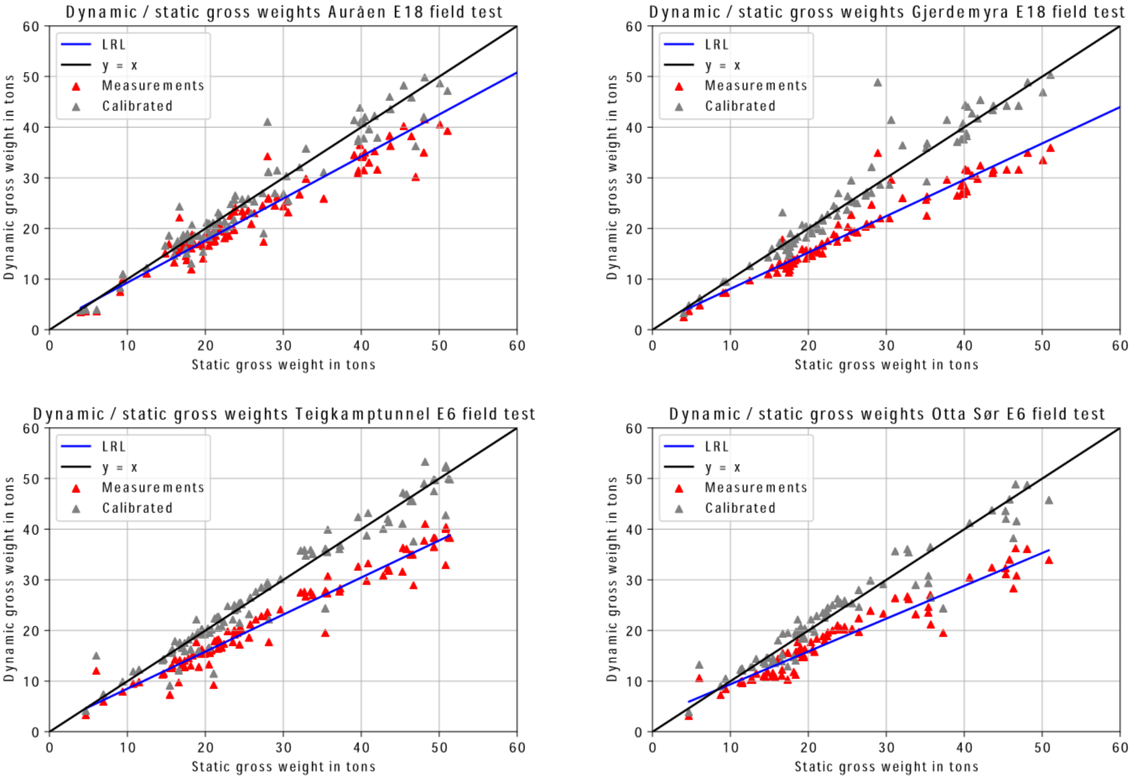

Figure 5 Overview of the field test and calibration results

In order to improve the raw data quality, the previously presented calibration method (see Eq. 1) was applied to the raw ATK data sets. The calibrated data is shown in Figure 5 as grey triangles. In all four cases the data quality has improved after the calibration process. The calibrated measurements are closer to the actual measured static weights. To study the detailed effects of the calibration method, a closer assessment of the measurement errors is needed. Therefore, Table 4 gives a more detailed overview about the observed errors during the field test studies and after the calibration.

The errors in Table 4 proof the previously observed underestimation of the static vehicle weights by the ATK sensor. In addition, the results from Figure 5 seem to indicate visually that the calibration method is indeed improving the data quality. The calibrated measurements are located close to the x = y line which is representing an ideal WIM system. The mean errors for the raw data sets are between -12,3% and -24,3%. The standard deviation error increases for the calibrated data set due to the increase of the mean value for the calibrated data set by multiplying it with a calibration factor (e.g. 1,20). Each ATK point is calibrated with its individual calibration factor. A detailed description of that process can be found in chapter 3.4.

Most of observed ATK data fulfils the accuracy requirements for the COST 323 accuracy class C or D+. According to COST 323, data that fulfills the criteria of these classes is good enough for being used for detailed statistical studies, which meets the requirements of this project.

Table 4 Errors of the raw and calibrated data for the ATK points mentioned in Figure 5

	n	Mean error	SD error
Auråen	89	-12,3%	11,24%
Auråen cal.	89	-0,59%	12,79%
Gjerdemyra	85	-24,3%	8,29%
Gjerdemyra cal.	85	-0,82%	11,64%
Teigkamp.	92	-20,9%	15,12%
Teigkamp. cal.	92	0,1%	18,85%
Otta	74	-20,41%	14,46%
Otta cal.	74	0,87%	17,77%

This part of the report gave an overview over some field test results. All presented ATK stations showed quite a satisfying performance and accuracy. The next part of the report will compare one of the ATK stations with good data quality to one station with poorer performance by using the developed data quality indicators. Possible causes for different data quality levels will be discussed.

4.2 Application of data quality indicators

This section applies the previously developed quality indicators on two different ATK data sets. Therefore, the raw data sets of the ATK stations Teigkamptunnel and Losna are analyzed. Both points are located in the Oppland region in central Norway. The ATK Teigkamptunnelen consists of two sensors, one at the beginning and on at the end of a tunnel. The presented results are based on the data from the sensor at the beginning of the tunnel.

Figure 6 gives and overview over the performance of the units during a field test, which was conducted in May 2017. Both points were investigated during the same field test since the distance between them is relatively close.

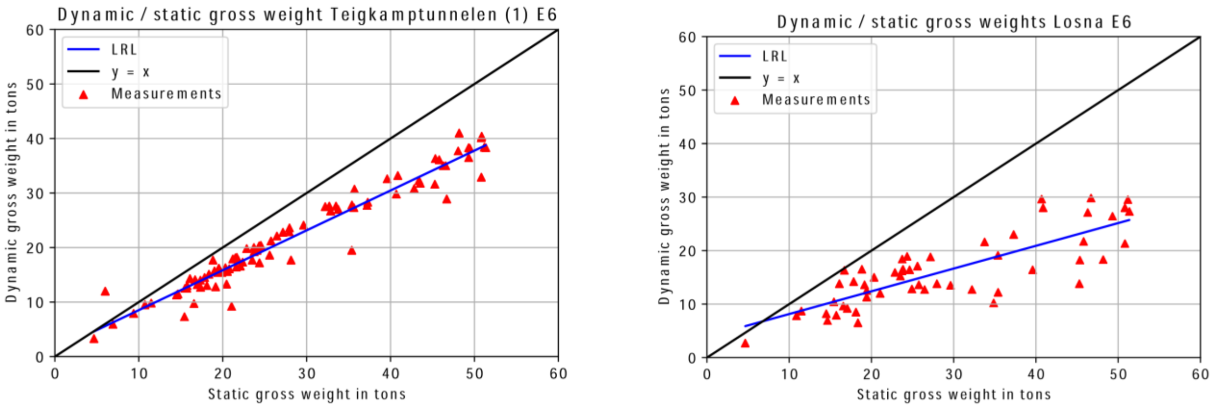

Figure 6 Field test results for ATK points Teigkamptunnelen and Losna along E6 in Oppland 2016

Figure 6 is a plott the static against the corresponding dynamic weight data for different trucks, same as earlier presented in Figure 5. Figure 6 indicates a difference in accuracy between the two sensors. Both units are underestimating the actual static weight. Data from the Losna sensor seems to have a poorer data quality and a higher spreading. Table 5 proofs these visual impressions by comparing the previously indicated quality indicators of the two ATK stations.

Table 5 Data quality indicators for ATK stations Teigkamptunnelen and Losna

	Recommended range	Teigkamp-tunnel	Losna
1st axle weight [t]	5,0 – 9,0	5,9	3,6
Standard deviation of 1st axle weight	max. 25%	16%	38%

Table 5 shows the corresponding numerical values to the graphs in Figure 6. Since both average axle weights for the first axle of a CVC vehicle are under 7.0 tons this does indicate the underestimation of the sensor. The standard deviation of that value is indicating the spreading of the data. The values for the ATK Teigkamptunnelen are within the recommended range, while the values for the ATK unit Losna are not.

The reason for poor data quality for weight data from ATK units can have various reasons. A couple of indicators for a poor data quality of ATK weight data were experienced during the project:

- use of old data logging units (especially DataRec 410)
- use of round instead of flat piezoelectric cables
- uneven road surface before the ATK unit

The old data logging unit DataRec 410 are about to be replaced by newer units such as Axspeed 200 during the next years. Also the round piezo electric cables are being more and more replaced by flat cables, which deliver a better weight data quality. The road segment within 200 meters in front of the ATK point Losna is rather uneven, which is probably the main reason for the poor data quality.

4.3 Long term data evaluation

The calibration method was afterwards applied to raw data, which was collected by three different ATK stations during a period of 12 months. Two of these stations (Gjerdemyra & Otta) were already mentioned in previous tests within this report and in addition, a third one was added (Storsand). Table 6 gives an overview of the amount of calibrated vehicle weights for each of the ATK stations.

Table 6 Overview over registered and for further tests used vehicles at various ATK stations

Axle configuration	Gjerdemyra	Otta	Storsand
Detected vehicles	1 708 376	1 430 394	1 430 097
2 axle vehicles	1 472 052	1 216 334	1 310 661
6 axle vehicles	70 875	50 487	26 255
6 axle semi-trailers	49 793	33 604	17 297

Over a period of 12 months, between 1.7 and 1.4 million vehicles were detected and among them between 70 000 and 26 000 were six axle trucks. Figure 7 shows the calibrated gross weight distribution for all six axle trucks at these stations as a kernel density estimation plot.

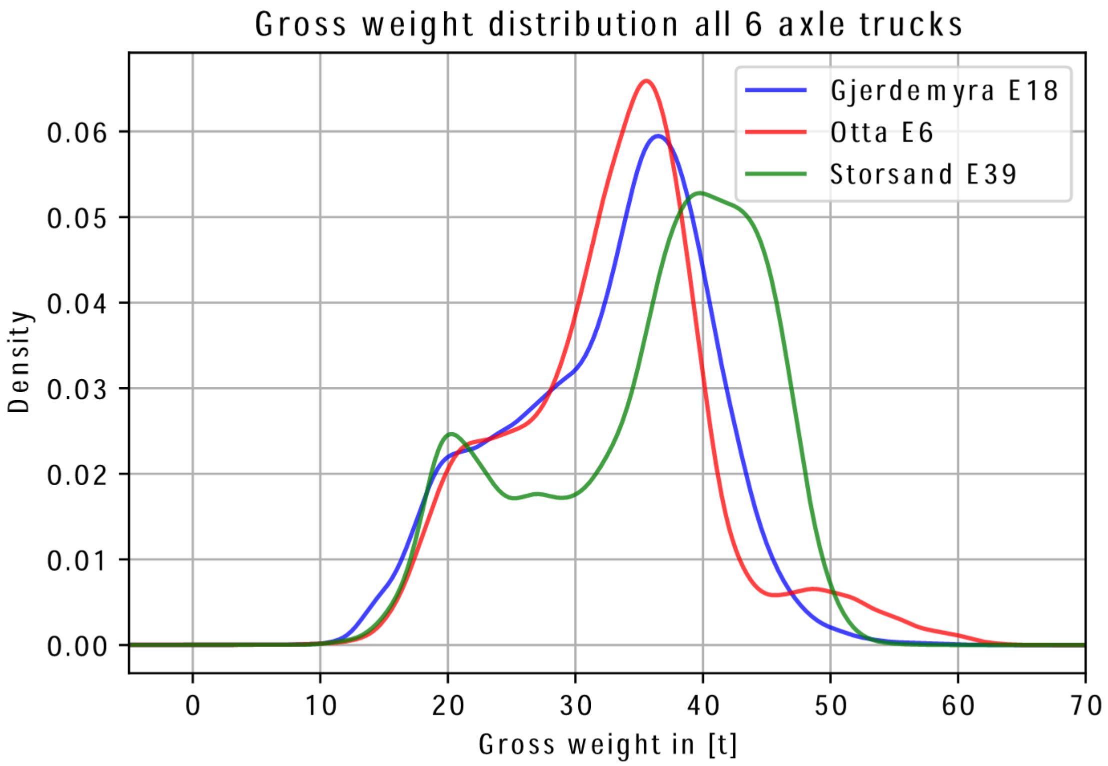

Figure 7 Gross weight distribution of six axle trucks at ATK points Gjerdemyra, Otta and Storsand

A kernel density estimation plot is a statistical method to estimate the probability density function of a random variable, which is in that case the vehicle gross weight. The probability density function is used to specify the probability of a certain gross weight of a vehicle to all other vehicles within that class.

The three graphs are widely similar in their structure and in line with previous studied gross weight distribution of that vehicle category on the Norwegian road network. Nevertheless, the results show some interesting local characteristics of the plotted weight distributions. The number of vehicles between 50 and 60 tons gross weight seems to be slightly higher in Otta, compared to the other two stations. The reason for that are timber trucks, which have special permissions in that region to extend their gross weight up to 60 tons, while 50 tons is the legal weight limit for that vehicle category on the Norwegian road network.

4.4 Stability over time

Local field studies helped to evaluate the data quality of weight data from various ATK sensors for one day. Previous tests indicated that the data quality of one ATK point could change over time. A possible reason for these changes could be the influence of temperature on the accuracy of the measured data. The used piezoelectric cables are sensitive to temperature and thus might a change in air temperature have an impact on the data accuracy [6]. Asphalt is also a temperature sensitive material and the air and asphalt temperature do not have to be the same in location. Due to the lack of reliable asphalt temperature sets air temperatures were used for the further evaluations.

The impact of temperature was studied on the ATK point Gjerdemyra in Telemark. Therefore, raw weight data from the ATK point was compared to local air temperature for a period from July 2016 to June 2017. As weight data, the already introduced first axle of the CVC [six axle semi-trailer vehicles] was used and compared to local air temperature, provided by the Norwegian metrological institute. The results of that experiment are presented in Figure 8.

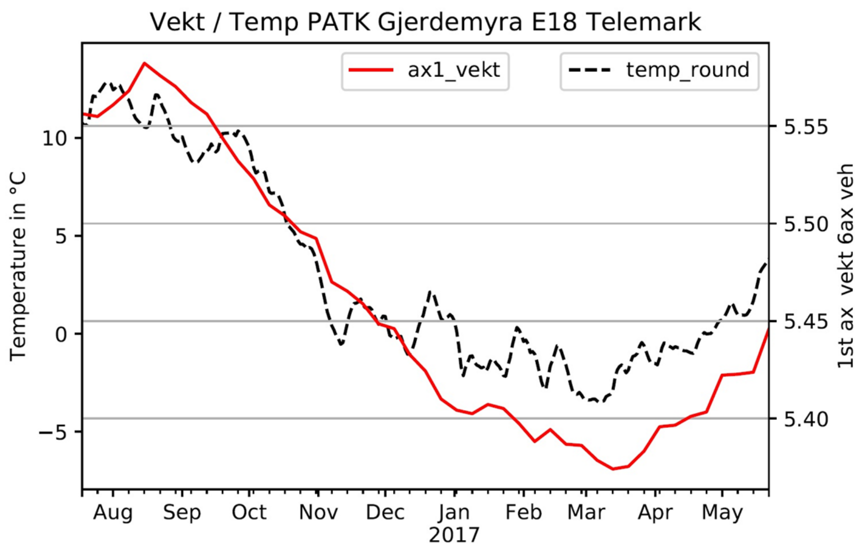

Figure 8 Temperature impact on ATK raw data accuracy [local air temperature compared to weight of first axle of six axle semi-trailer vehicles]

The red line shows the average weight for the first axle for the CVC and the dashed black line the local temperature. Both graphs do have a similar structure and the temperature does indeed seem to have an impact on the accuracy of weight data. The average weight of the first axle of the CVC is increasing with increasing temperatures and decreases during colder periods, for example within the period from November to April. All in all, is the effect of temperature on the data accuracy not as big as expected. The average temperatures in Gjerdemyra vary between -4° and +12° degrees Celsius. The corresponding axle weights are meanwhile varying within a range of +/- 100kg around a mean value of 5.45 tons.

The ATK point Storsandtunnelen was also investigated in terms of its data stability over time. Other than the ATK point Gjerdemyra is the point Storsandtunnelen less exposed to weather phenomena since it is located in the middle of a 3600m long tunnel. Figure 9 gives an overview over the registered axle weights for all axles of the vehicles from the CVC. The data accuracy was studied for a period of 12 month from January to December 2016.

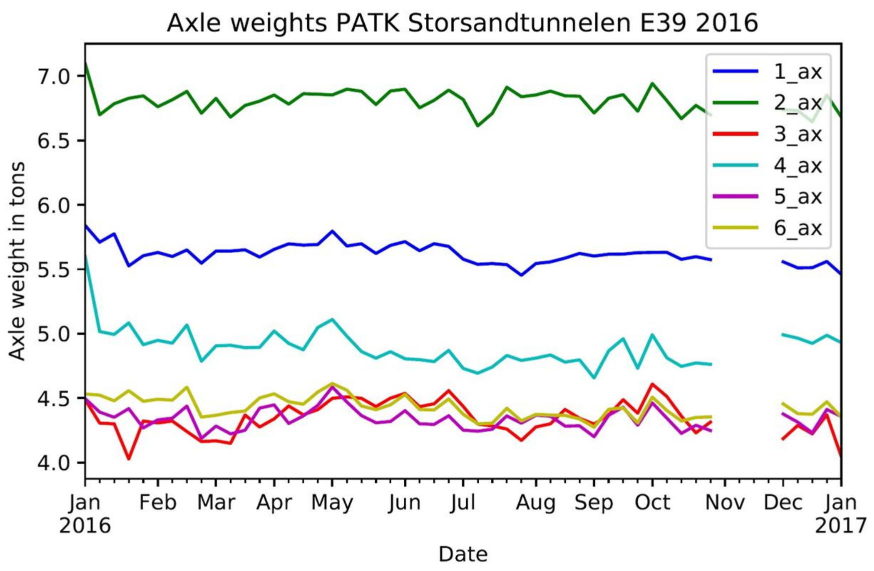

Figure 9 ATK data stability over time for all axels six axle semi-trailer vehicles at ATK Storsandtunnelen

The blue line is representing the average weight of the first axle of all CVC vehicles and has a mean value of 5.76 tons over the entire period. All axle weights are very stable and neither temperature nor other external effects seem to disrupt the accuracy within that period. The ATK data logger was calibrated in November 2016, which explains the gap in the data during the end of the year 2016. The calibration of ATK data loggers is just affecting the speed measurement system and does not have an impact on the collection of weight data. The weight data accuracy level did not change before and after calibration.

Besides the impact of temperature could also other effects influence the data quality over a certain period. Those impacts could for example be:

- Change of ATK data logger to newer version
- Change of piezoelectrical cables due to wear
- Repaving of the road and thus changes in the asphalt structure
- New filling material for the gap in the asphalt, over the piezoelectric cables

Some of these effects can be observed at the ATK point Buktamo Sør along E6 in Troms in northern Norway. Figure 10 gives an overview over the performance of that sensor for the period between May and December 2017.

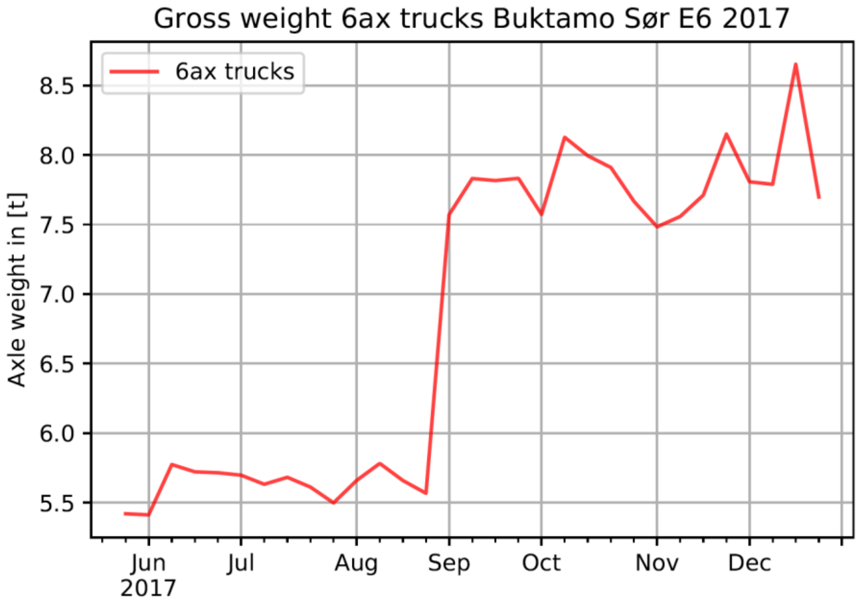

Figure 10 ATK data stability over time for all axels six axle semi-trailer vehicles at ATK Buktamo Sør

The red graph shows the average weight of the first axle of a six axle semi-trailer truck. The initial measured weight is relative stable around a mean of 5.8 tons between May and the end of August 2017. In late august were both, the data logger and corresponding cables changed, and the average weight increased to a mean of 8.1 tons for the following period. The sensor in general seems to deliver usable data sets in both time periods and thus an adjustable post processing and calibration method with a dynamic calibration factor can compensate these changes over time. These results underline the importance of a time-based evaluation of weight data from ATK stations and an eventual adjustment of the calibration method over time.

5. Summarizing conclusion

The project evaluated the accuracy of weight data from piezoelectric based ATK sensors in Norway. Initial field tests provided an overview over the performance of the sensors and helped to establish a calibration and data quality evaluation method. The proposed calibration method was applied to improve ATK raw data sets.

This study indicated a systematic error between the dynamic weights from an ATK sites and parallel measured static weights. These errors appeared both, in traditional piezo-based WIM systems as well as at the piezo-based ATK sites. The dynamic weight data from ATK sites was found to be accurate enough for different applications. The evaluation of dynamic weight data based on the COST 323 guideline categorized the data for example as accurate enough for statistical analytics. Some ATK sensors are within a similar error range as commercial piezo electrical WIM equipment which was tested by the NPRA before.

Since the main goal of this project is not to enforce weight limits by using ATK-WIM sensors, but to gather statistical relevant information about the weight of vehicles traveling on different parts of the Norwegian road network, these results are promising for further research approaches such as the application of generated data in the field of pavement and road design.

Using the weight of the first axle of a six axle semi-trailer vehicle as a weight data quality indicator could be an interesting method for providing information about the performance of the sensors without implementing a field test at a local weigh station. First tests with a developed calibration factor showed indeed an improvement of the accuracy of dynamic weights.

The developed quality indicator based on the mean weight of the first axle of a six-axle semi-trailer vehicle provided similar information about the performance of the ATK equipment as the field test did. This approach might be used in the future for initial quality checks on ATK weight data in Norway. It could provide information about the weight data collection performance of the particular ATK unit. Since the data is in many cases showing little variance, a calibration based on a quality indicator seems to be possible. Further research will provide more knowledge about calibration methods and will isolate certain factors, influencing the accuracy of ATK WIM systems.

Nevertheless, these are just the first experimental steps into the usage of weight data from ATK units. Future studies should apply the developed methods to even more ATK sites across the country to gain further knowledge.

6. Further research

The project evaluated whether weight data from ATK sensors could be used for weight statistics. The developed methods helped to analyze the sensors performance in terms of the data quality and its stability over time. Little research was done so far on evaluation why particular senor delivered good or poor data quality. Interesting approaches for further research could therefore be:

- Evaluate the effect of asphalt structure and layers on data quality and accuracy
- Detailed investigation of the evenness of the road surface before ATK sensor and its impact on data quality
- More detailed investigation of piezoelectric cables, data loggers and filling material
- Observe the performance of one sensor over a longer period with several field tests

7. Exemplary overview of results

The following chapter is showing results of the ATK weight data analytics, generated from different ATK points all over Norway. The structure of the results for each station is presented widely similar but not all analytics were implemented for each point. There are for example station without conducted field tests. The presented results are based on calibrated raw data from the ATK units.

7.1 ATK Gjerdemyra

The ATK point Gjerdemyra is located in Telemark around 45 km south-west of Prosgrunn along the motorway E18 in northern-eastern direction. The related static weights during the field study were collected at Østerholtheia weight station. Figure 11 gives an overview of the location of the ATK unit and the corresponding control station.

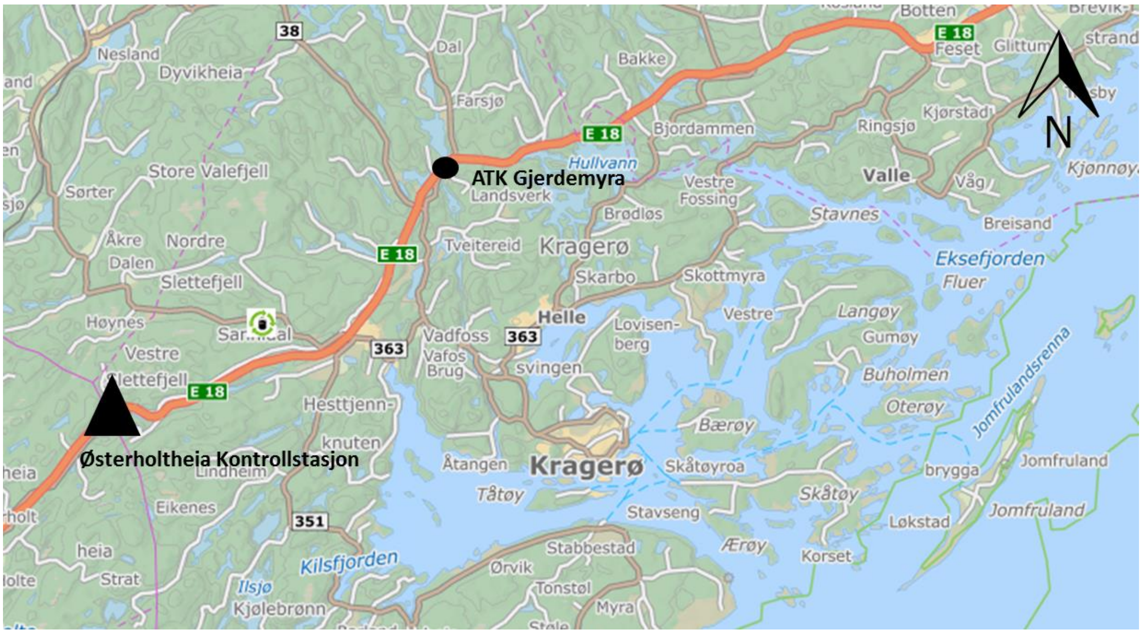

Figure 11 Location ATK Gjerdemyra and Østerholtheia control station

Raw data from Gjerdemyra was analyzed for a period of 17 month from January 2016 to May 2017. Table 7 gives an overview over the traffic volumes within that period.

Table 7 Vehicles Gjerdemyra E18 2016 -2017

Axle configuration	Gjerdemyra
Detected vehicles	1 708 376
2 axle vehicles	1 472 052
6 axle vehicles	70 875
6 axle semi-trailers	49 793

Figure 12 shows the distribution functions of all axles of 6 axle vehicles at Gjerdemyra. The corresponding mean values and the standard devitaion og each axle weight is presented in Table 8. Both values (mean & standard deviation of 1st axle) are within the previously recommended range of the qulity indicator crieterias.

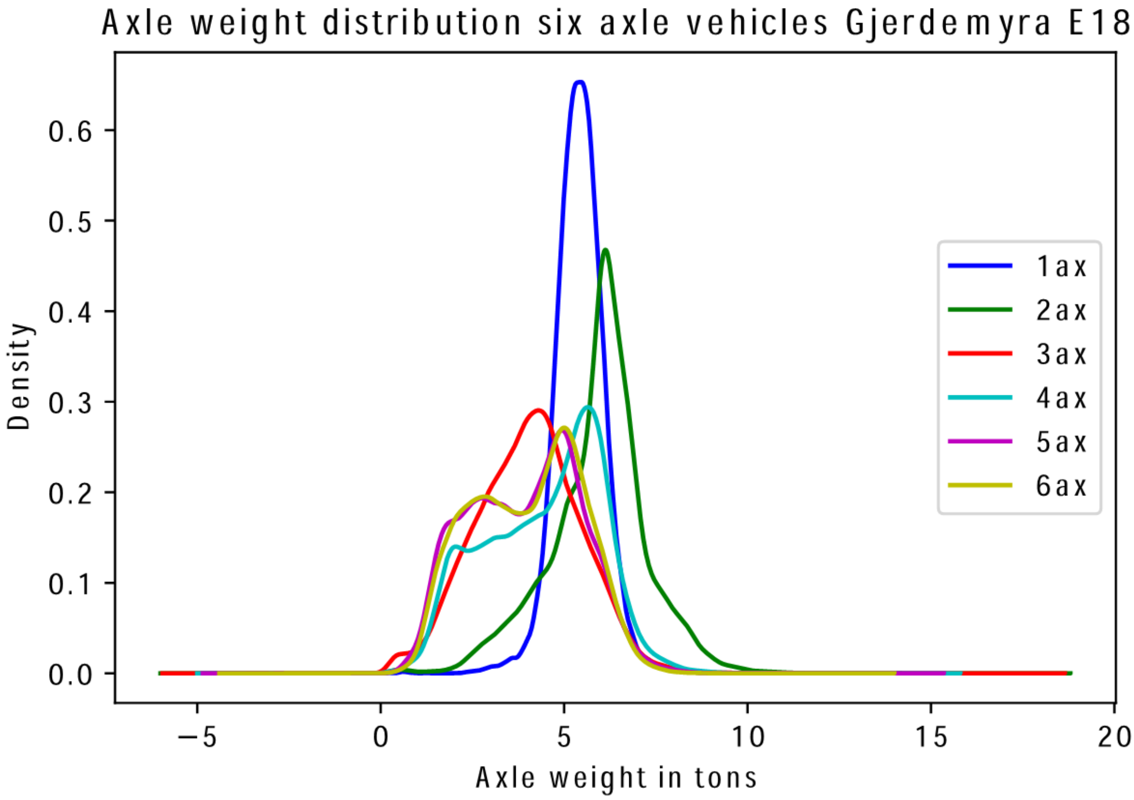

Figure 12 KDE plot raw axle weight data 6 axle vehicles Gjerdemyra E18

Table 8 Axle characteristics 6 axle vehicles (raw data)

Axles	Mean in t	STD in t
1 axle	5.86	0.61
2 axle	6.93	1.41
3 axle	4.53	1.52
4 axle	4.86	1.53
5 axle	4.31	1.46
6 axle	4.30	1.45

The static gross weights showed in Figure 13 were collected during the field study at Østerholtheia weight station. The static weights are compared to ATK raw data and calibrated data.

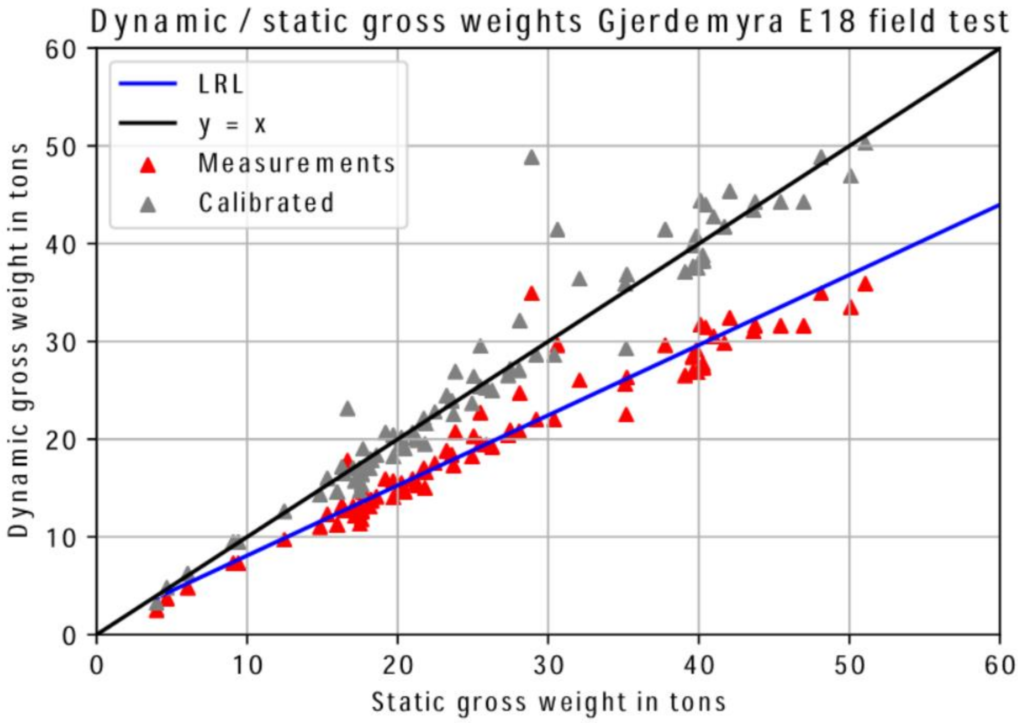

Figure 13 Static / raw and calibrated dynamic gross weights Gjerdemyra E18

Table 9 gives an overview over the corresponding results. The data quality improves after calibration and the mean error decreases from -24,3% to -0,82%.

Table 9 Results calibration of field test data with developed calibration method

	N	Mean error	SD error
Gjerdemyra	85	-24,3%	8,29%
Gjerdemyra cal.	85	-0,82%	11,64%

Axle statistics of vehicles at Gjerdemyra are presented in Table 11 and Table 12.
Table 10 gives an overview over the total amount of axles per truck and vehicle. The classification is based on their weight. Every vehicle, heavier then 3,5t is categorized as a heavy vehicle / truck. Table 10 compares also the shares with the length-based classification system DataInn, which is used on many Norwegian roads.

Table 10 Axels per vehicle/truck Gjerdemyra E18

Vehicles	Axles per vehicle	Trucks	Axels	Axels per truck	% Trucks	% DataInn
1 708 376	2.47	237 902	1 076 614	4.52	13.9 %	18 %

Table 11 and Table 12 present the shares of vehicles / trucks with double or triple bogie axels. The double and triple bogie axels were classified based on the definition of theses axle groups from the Norwegian veglista. Table 11 gives an overview over the total amount of registered vehicles and the share of trucks. The calibrated weight data from the ATK unit was used to categorize the vehicles. As mentioned earlier, was every vehicle heavier then 3,5 tons defined as a truck in that case. The following rows describe the total and percentage amount of 2- and 3- bogie axles per truck.

Table 11 2 /3-bogie axels per truck Gjerdemyra E18

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 708 369	234 125	13.70%	175 589	75.00 %	77 316	33.02 %

Table 12 is showing the percental share of 2- or 3-boggi axles not per truck as in Table 11 but per all registered vehicles.

Table 12 2 /3-bogie axels per vehicle Gjerdemyra E18

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 708 369	234 125	13.70 %	175 589	10.28 %	77 316	4.53 %

Figure 14 and Figure 15 are showing the probability density functions for the weight of 2- and 3-bogie axles at the ATK point.

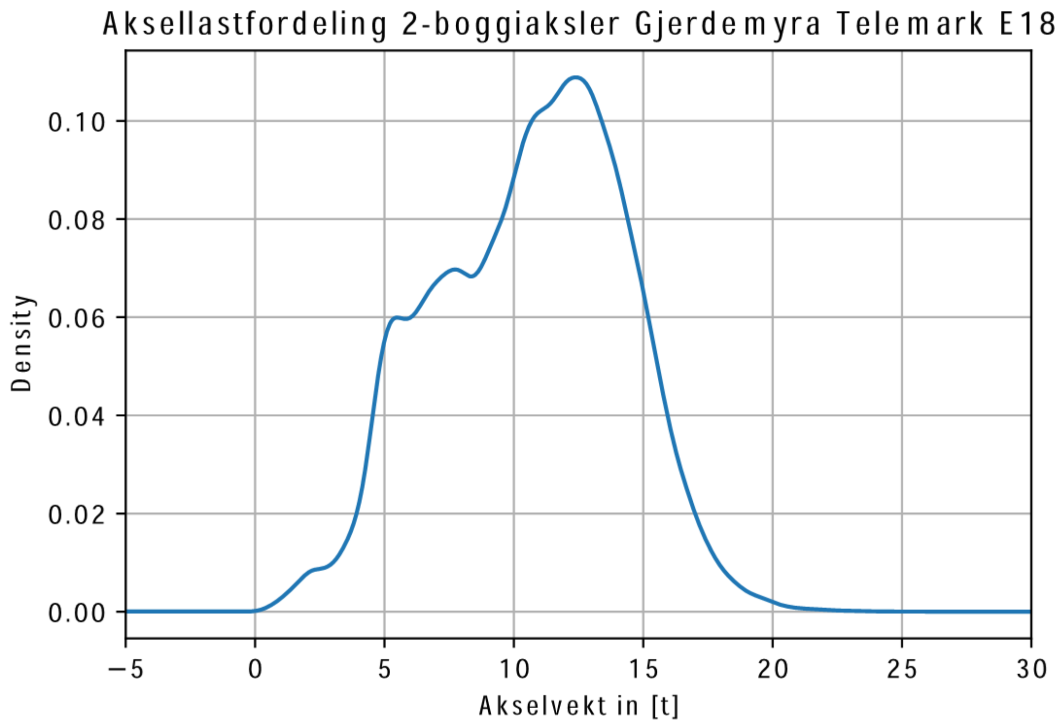

Figure 14 Weight distribution of 3-boggi axles at ATK Storsandtunnelen E39 for 2016

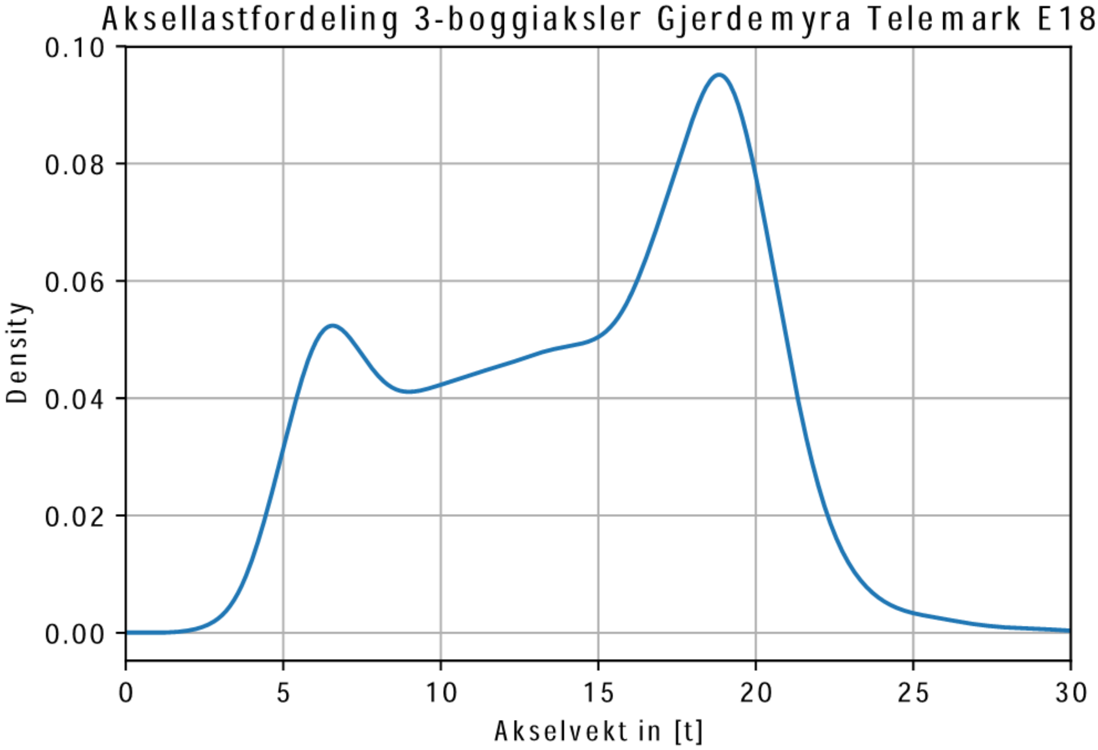

Figure 15 Weight distribution of 3-boggi axles at ATK Storsandtunnelen E39 for 2016

7.2 ATK Otta

The ATK point Otta Sør is located in Oppland around 100 km north of Lillehammer along the motorway E6 in south going direction. Figure 16 gives an overview over the location of the ATK point and the corresponding control station.

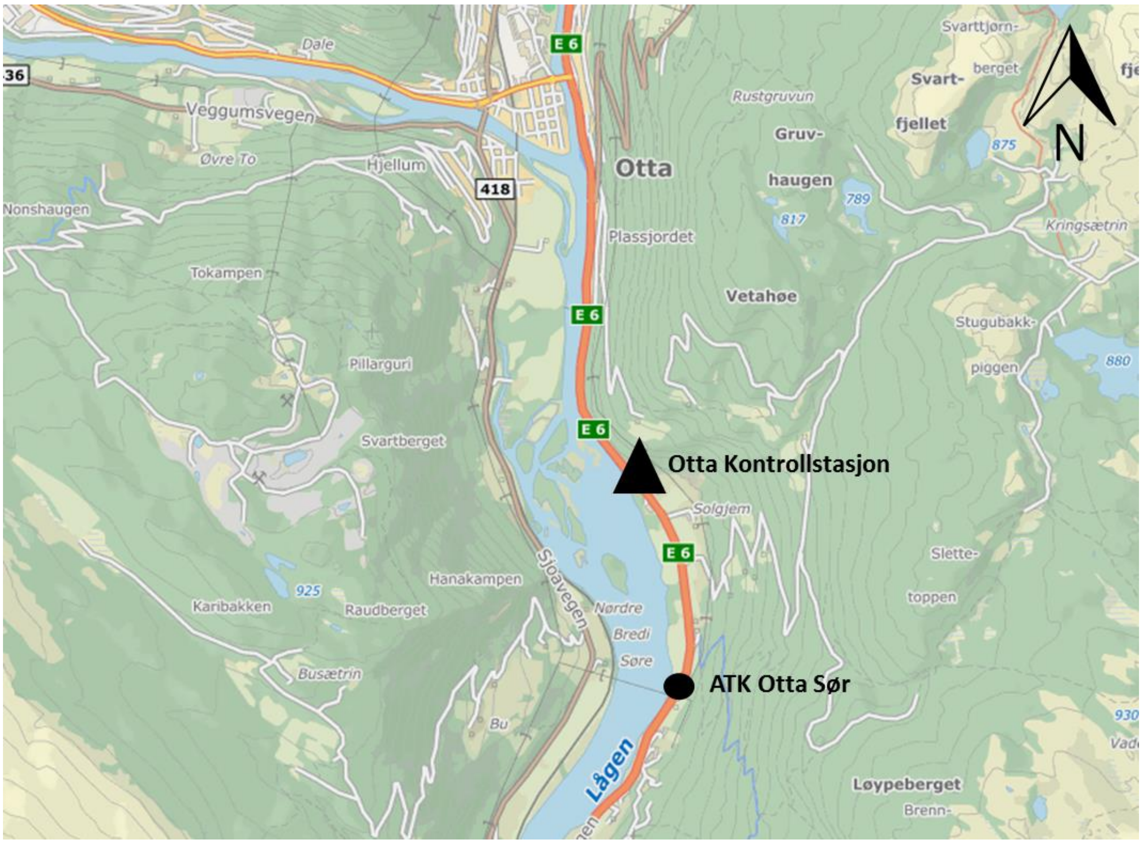

Figure 16 Location ATK Otta Sør and Otta control station

The related static weights during the field study were collected at the Otta weight station which is just a few hundred meters north of the ATK point. Raw data from Otta Sør was analyzed for a period of 22 month from January 2016 to October 2017. Table 13 gives an overview over the traffic volumes within that period.

Table 13 Vehicles Otta E18 2016

Axle configuration	Otta
Detected vehicles	1 430 394
2 axle vehicles	1 216 334
6 axle vehicles	50 487
6 axle semi-trailers	33 874

Figure 17 shows the distribution functions of all axles of 6 axle vehicles at Otta Sør. The corresponding mean values and the standard devitaion of all axle weights are presented in Table 14. Both values (mean & standard deviation of 1st axle) are within the previously recommended range of the qulity indicator crieterias.

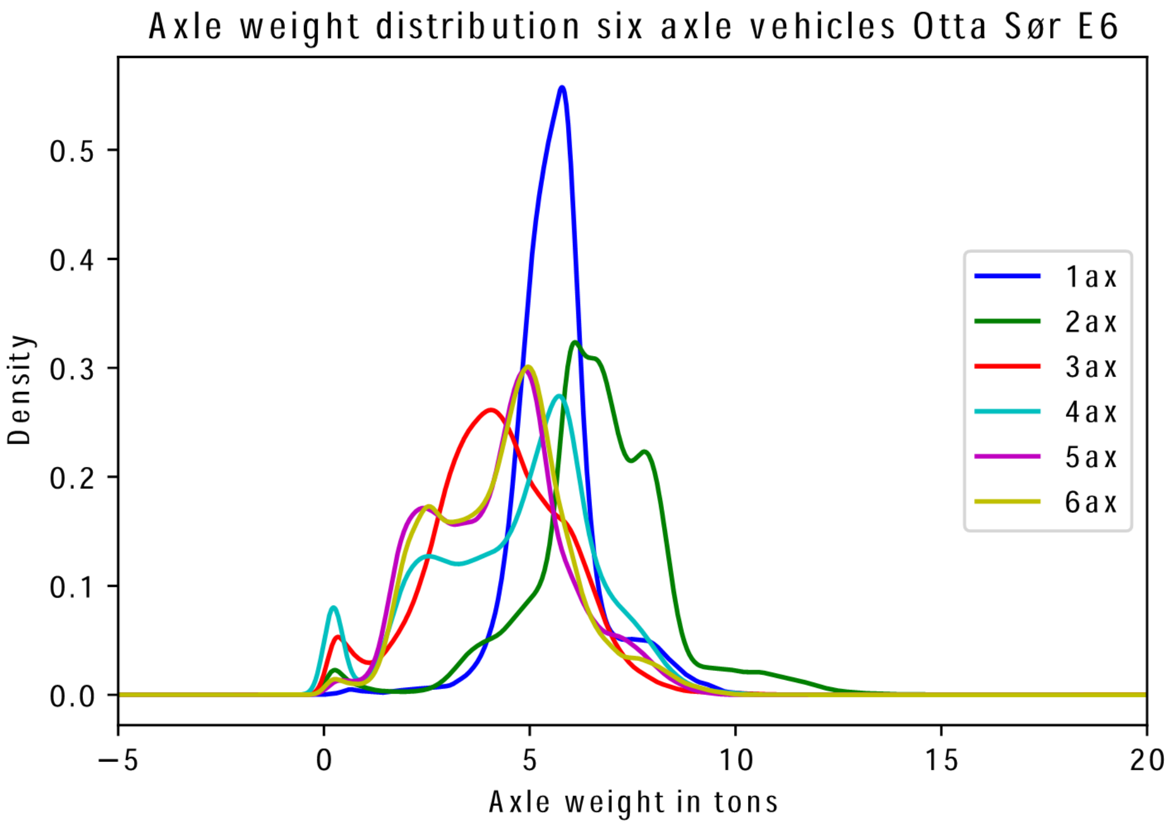

Figure 17 KDE plot raw axle data six axle vehicles Gjerdemyra E18

Table 14 Axle characteristics six axle vehicles (raw data)

Axles	Mean in t	STD in t
1 axle	5.61	0.96
2 axle	6.67	1.63
3 axle	4.30	1.59
4 axle	4.41	1.88
5 axle	4.22	1.54
6 axle	4.40	1.57

The static gross weights showed in Figure 13 were collected during the field study at Østerholtheia weight station. The static weights are compared to ATK raw data and calibrated data.

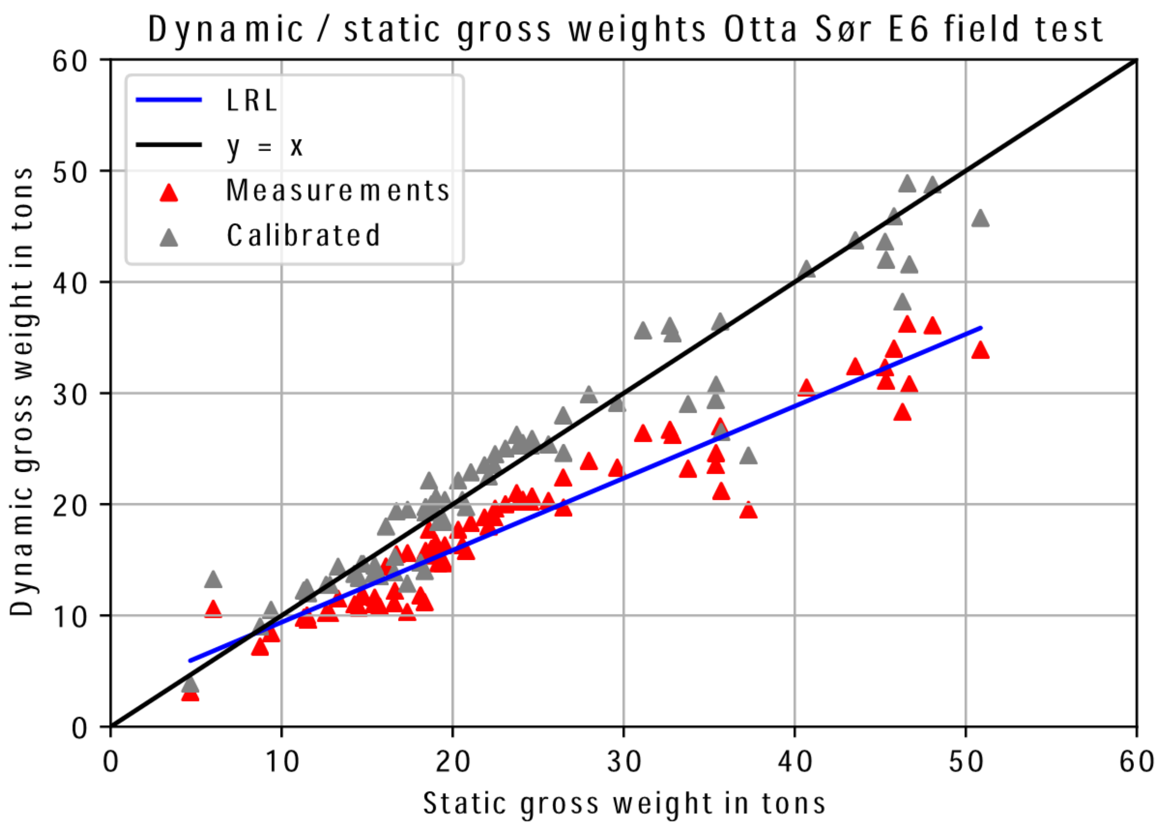

Figure 18 Static / raw and calibrated dynamic gross weights Otta E6

Table 15 gives an overview over the corresponding results. The data quality improves after calibration and the mean error decreases from -19,4% to -0,84%.

Table 15 Results calibration of field test data with developed calibration method

	n	Mean error	SD error	AC
Otta Sør	74	-19,4%	14,45%	D
Otta Sør cal.	74	-0,84%	16,61%	D

Axle statistics of vehicles at Otta are presented in
Table 16,Table 17 and Table 18.

Table 16 gives an overview over the total amount of axles per truck and vehicle. The classification is based on their weight.. Every vehicle, heavier then 3,5t is categorized as a heavy vehicle / truck.

Table 16 compares these shares with the length-based classification system DataInn, which is used on many Norwegian roads.

Table 16 Axels per vehicle/truck Otta Sør E6

Vehicles	Axles per vehicle	Trucks	Axels	Axels per truck	% Trucks	% DataInn
1 430 387	2.32	203 691	846 550	4.16	14.2 %	19.0 %

Table 17 and Table 18 present the shares of vehicles / trucks with double or triple bogie axels. The double and triple bogie axels were classified based on the definition of theses axle groups from the Norwegian veglista. As mentioned earlier, was every vehicle heavier then 3,5 tons defined as a truck in that case. The following tables describe the total and percentage amount of 2- and 3- bogie axles per truck.

Table 17 2 /3-bogie axels per truck Otta Sør E6

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 430 387	197 008	13.77 %	153 425	77.88 %	54 080	27.45 %

Table 18 is showing the percental share of 2- or 3-boggi axles not per truck as in Table 17 but per all registered vehicles.

Table 18 2 /3-bogie axels per vehicle Otta Sør E6

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 430 387	197 008	13.77 %	153 425	10.73 %	54 080	3.78 %

Figure 19 and Figure 20 are showing the probability density functions for the weight of 2- and 3-bogie axles at the ATK point.

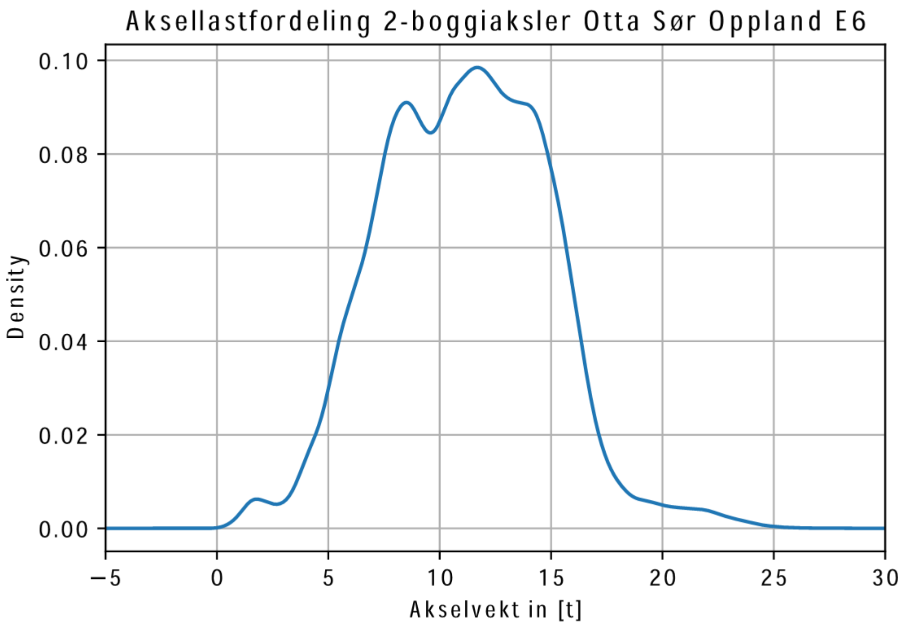

Figure 19 Weight distribution of 2-boggi axles at ATK Otta Sør E6 for 2016

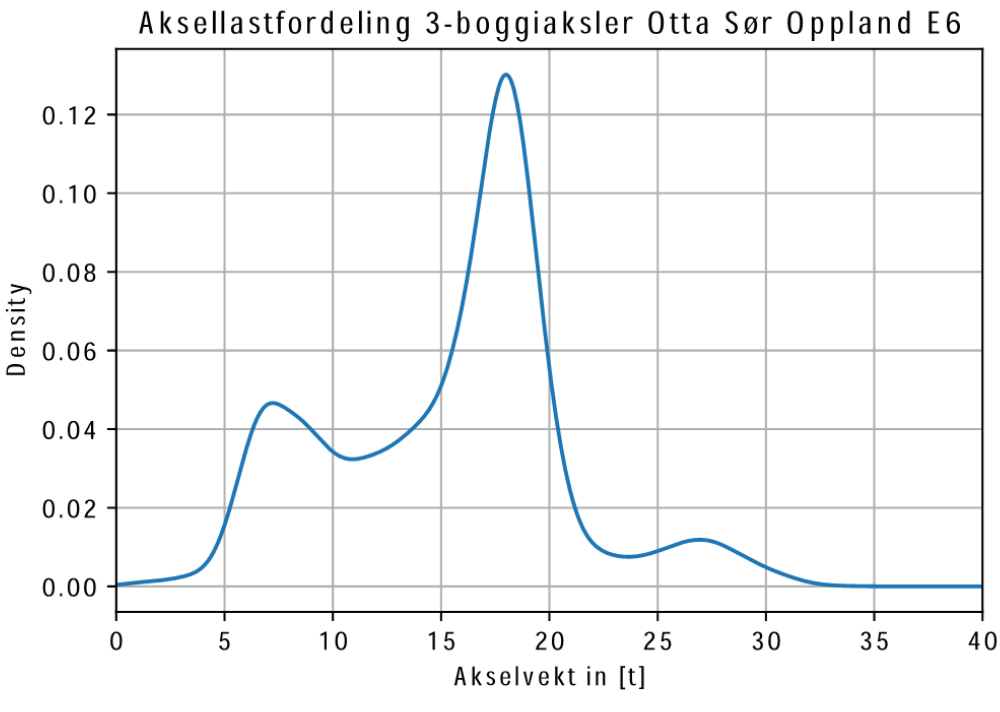

Figure 20 Weight distribution of 3-boggi axles at ATK Otta Sør E6 for 2016

7.3 ATK Teigkamptunnel

The ATK point Teigkamptunnelen is located in Oppland around 80 km north of Lillehammer along the motorway E6 in south going direction. The ATK Teigkamptunnelen consists out of two ATK points, one at the beginning and one at the end of a tunnel. The ATK unit is measuring the average speed between the two ATK points of all vehicles. The data for the following evaluation came from the ATK unit at beginning of the tunnel (ATK-ankomst).

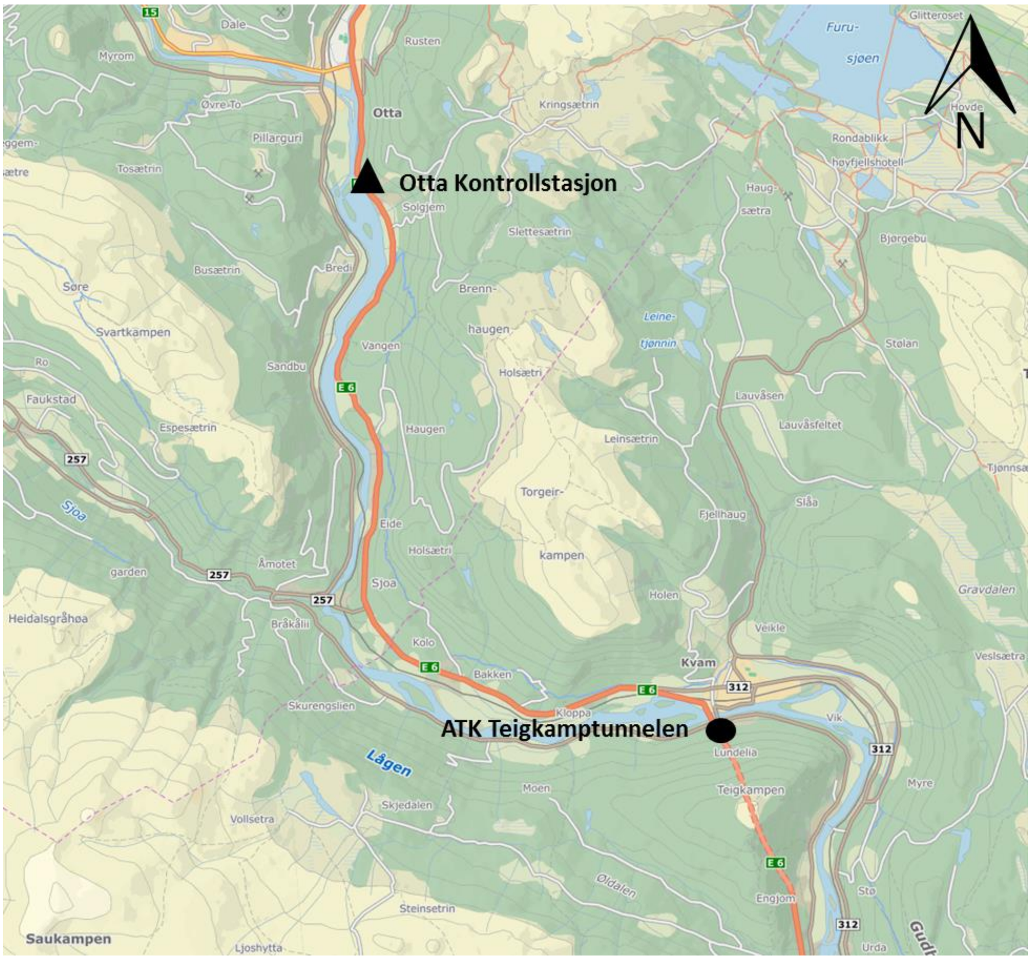

Figure 21 Location ATK Teigkamptunnel and Otta control station

Figure 21 gives an overview over the location of the ATK point and the corresponding control station. Table 19 gives an overview over all registered vehicles at the ATK station in the observed period from January to July 2017.

Table 19 Vehicles Teigkamptunnel E6 2017

Axle configuration	Teigkamptunnel
Detected vehicles	344 082
2 axle vehicles	281 348
6 axle vehicles	19 405
6 axle semi-trailers	13 193

The following results of the field test in Figure 22 and Table 20 were collected during a field study in May 2017.

Table 20 Results calibration of field test data with developed calibration method

	n	Mean error	SD error	AC
Teigkamptunnel	92	-20,98%	15,1%	D
Teigkamptunnel cal.	92	-0,91%	18,5%	D

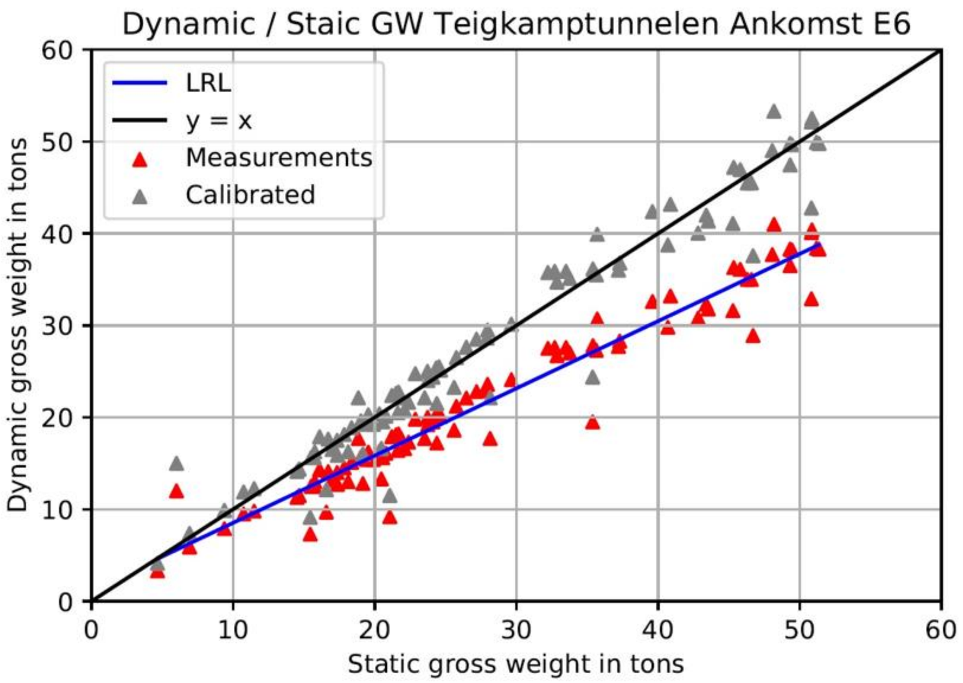

Figure 22 Static / raw and calibrated dynamic gross weights Teigkamptunnelen E6

Axle statistics of vehicles at Teigkamptunnelen are presented in Table 21, Table 22 and Table 23. Table 21 gives an overview over the total amount of axles per truck and vehicle. The classification is based on their weight. Every vehicle, heavier then 3,5t is categorized as a heavy vehicle / truck. Table 21 compares these shares with the length-based classification system DataInn, which is used on many Norwegian roads.

Table 21 Axels per vehicle/truck Teigkamptunnel E6

Vehicles	Axles per vehicle	Trucks	Axels	Axels per truck	% Trucks	% DataInn
334 082	2.49	56 699	264 953	4.44	17.4%	22.6 %

Table 22 and Table 23 present the shares of vehicles / trucks with double or triple bogie axels. The double and triple bogie axels were classified based on the definition of theses axle groups from the Norwegian veglista. The calibrated weight data from the ATK unit was used to categorize the vehicles. As mentioned earlier, was every vehicle heavier then 3,5 tons defined as a truck in that case. The following tables describe the total and percentage amount of 2- and 3- bogie axles per truck.

Table 22 2 /3-bogie axels per truck Teigkamptunnel E6

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
344 082	59 209	17.21 %	47 825	80.77 %	17 961	30.33 %

Table 23 is showing the percental share of 2- or 3-boggi axles not per truck as in Table 22 but per all registered vehicles.

Table 23 2 /3-bogie axels per vehicle Teigkamptunnel E6

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
344 082	59 209	17.21 %	47 825	13.90 %	17 961	5.22 %

Figure 23and Figure 24 are showing the probability density functions for the weight of 2- and 3-bogie axles at the ATK point.

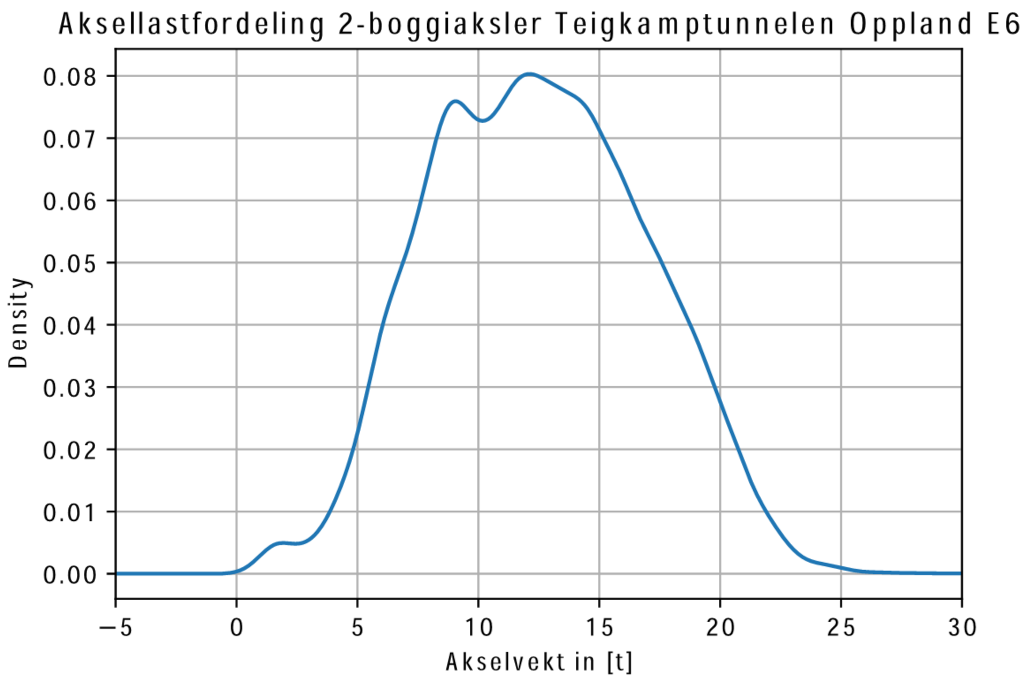

Figure 23 Weight distribution of 2-boggi axles at ATK Teigkamptunnelen E6 for 2017

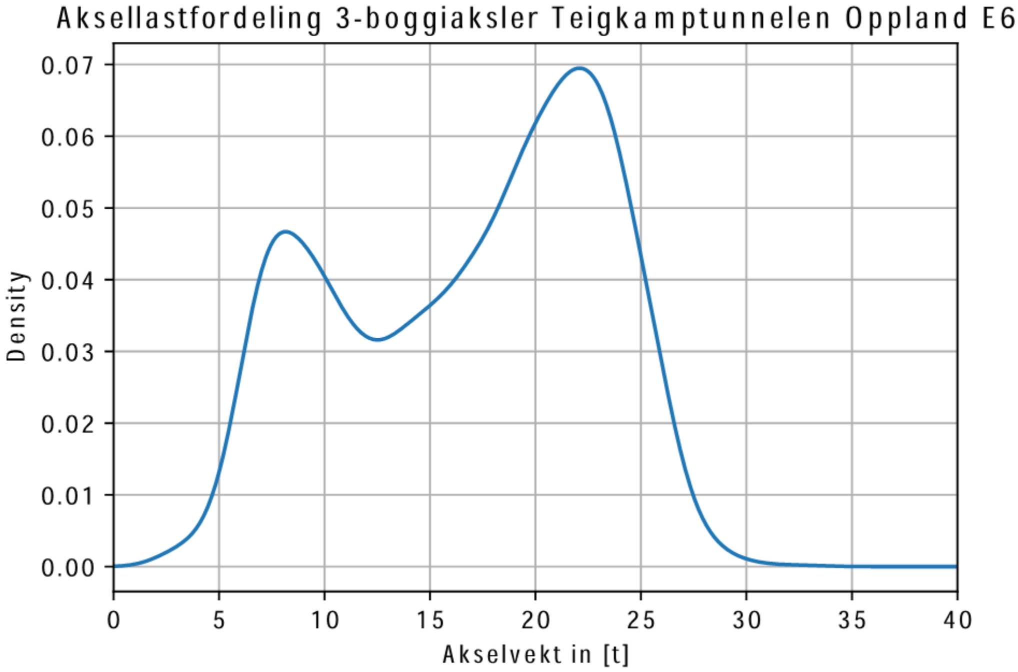

Figure 24 Weight distribution of 3-boggi axles at ATK Teigkamptunnelen E6 for 2017

7.4 ATK Auråen

The ATK point Auråen is located in Telemark around 40 km south-west of Prosgrunn along the motorway E18 in northern-eastern direction. The related static weights during the field study were collected at Østerholtheia weight station. Figure 11 gives an overview of the location of the ATK unit and the corresponding control station.

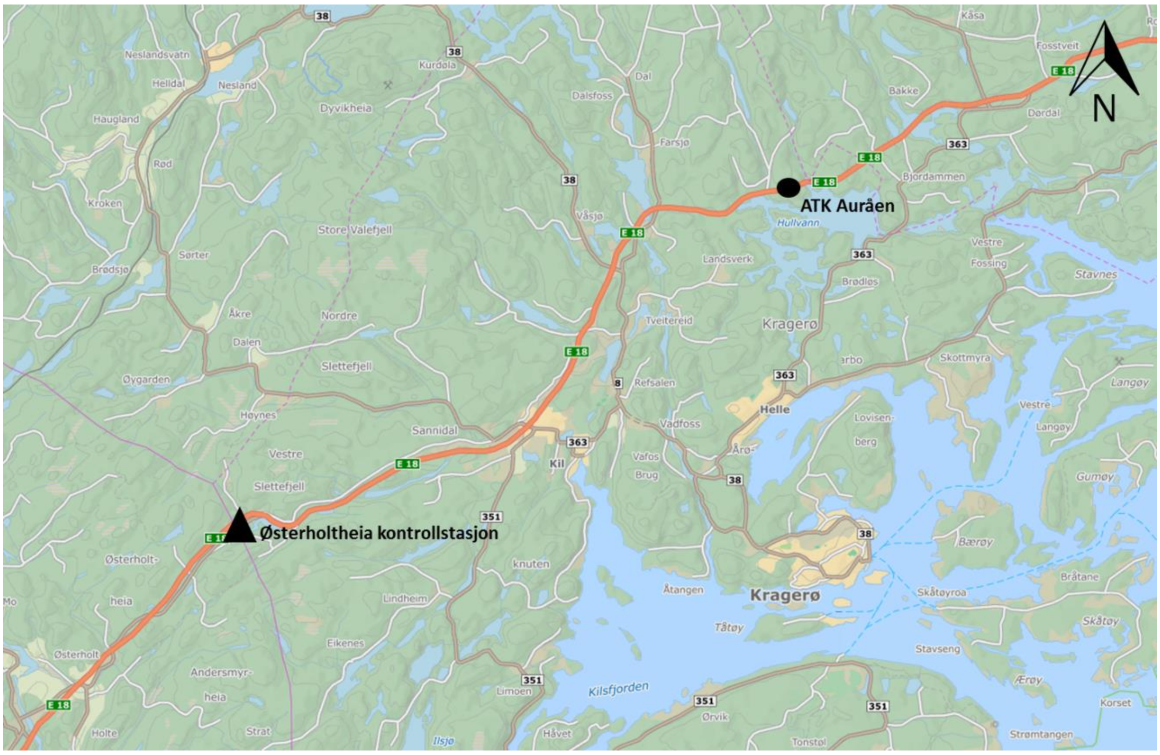

Figure 25 Location ATK Auråen

Figure 26 gives an overview over the conducted field test at Østerholtheia weight station where the registered static weights were compared to the dynamic ATK weights.

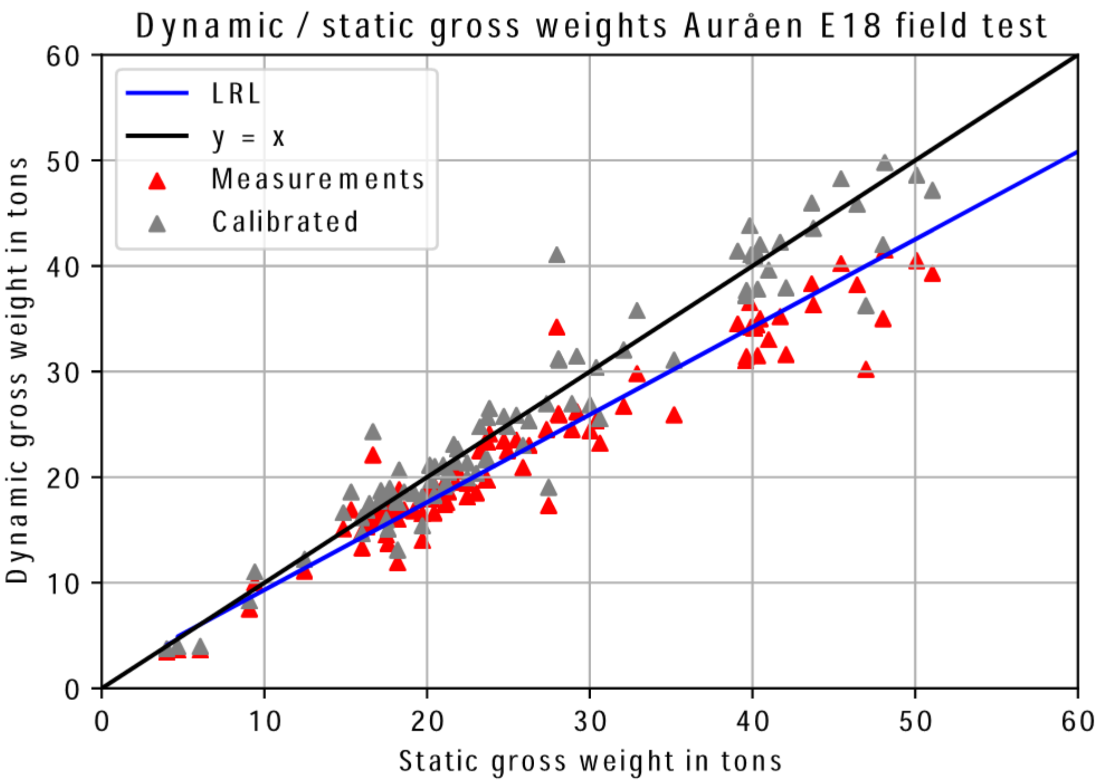

Figure 26 Static / raw and calibrated dynamic gross weights Auråen E18

Table 24 and Table 25 present the shares of vehicles / trucks with double or triple bogie axels. The double and triple bogie axels were classified based on the definition of theses axle groups from the Norwegian veglista. The calibrated weight data from the ATK unit was used to categorize the vehicles. As mentioned earlier, was every vehicle heavier then 3,5 tons defined as a truck in that case. The following tables describe the total and percentage amount of 2- and 3- bogie axles per truck and per vehicle.

Table 24 2 /3-bogie axels per truck Auråen E18

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 436 097	2.18	130 221	474 364	3.72	9.0 %	12 %

Table 25 is showing the percental share of 2- or 3-boggi axles not per truck as in Table 24 but per all registered vehicles.

Table 25 2 /3-bogie axels per vehicle Auråen

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 436 097	120 888	8.42 %	83 477	5.81 %	21 637	1.51 %

7.5 ATK Losna

The ATK point Losna is located in Oppland around 40 km north of Lillehammer along the motorway E6 in south going direction. Figure 27 gives an overview over the location of the ATK unit. The performance of the ATK unit was evaluated during a field test in May 2017 and in addition were the previous during the project developed data quality indicators used to evaluate the sensors performance.

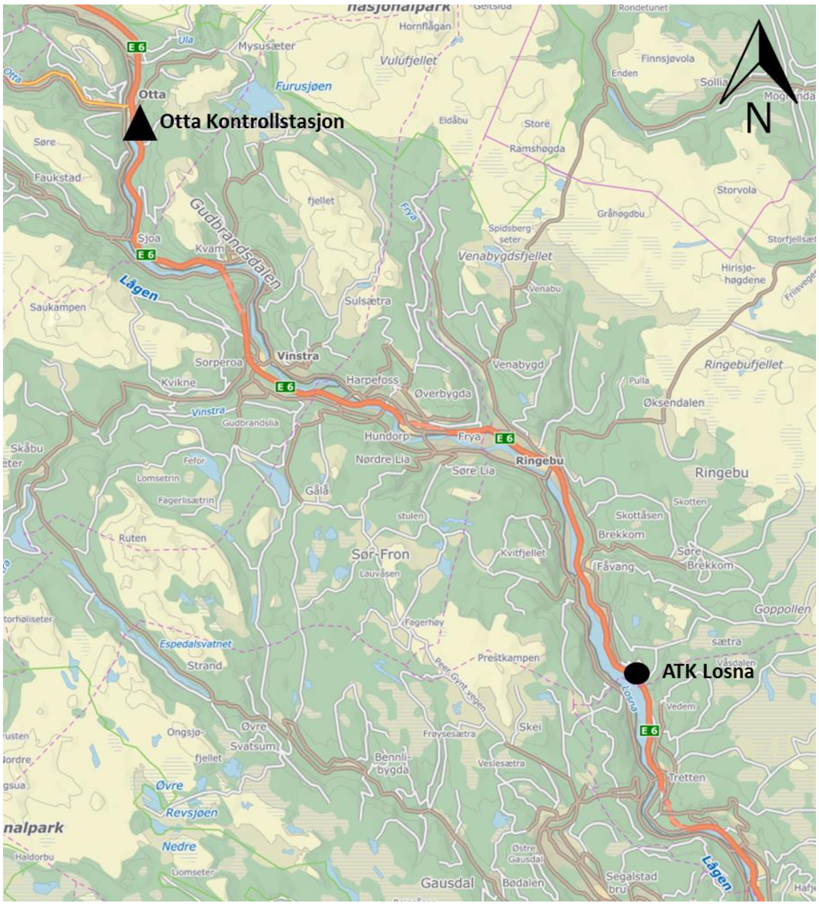

Figure 27 Location ATK Losna

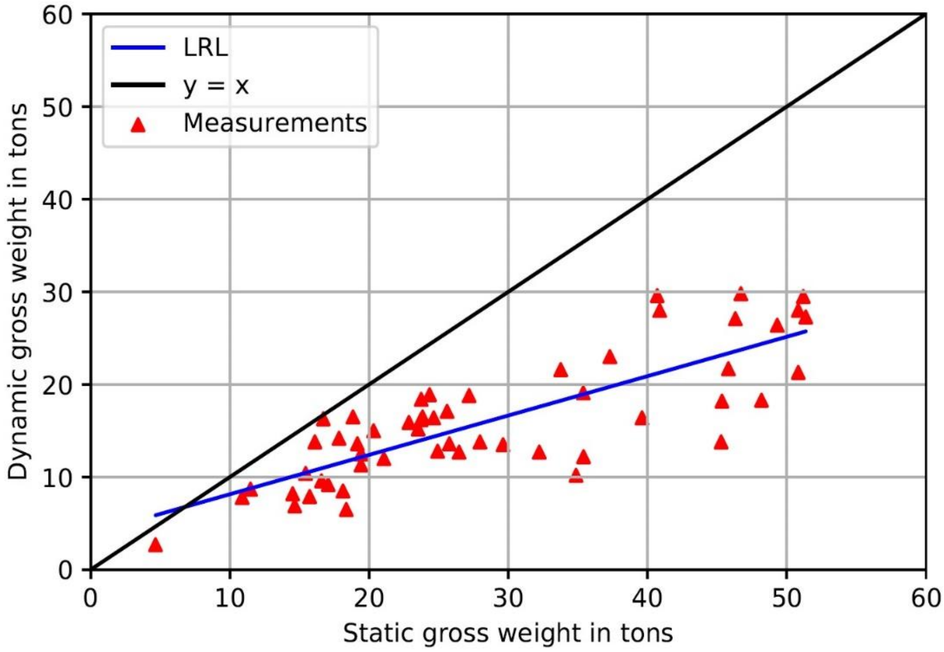

Figure 28 Static / raw and calibrated dynamic gross weights Losna E6

Figure 28 shows the results of the conducted field tests for the ATK unit Losna. As already discussed in chapter 4.2 is the quality level of weight data from that unit quite poor. The data has a high spreading and the dynamic weights are heavily underestimating the corresponding static weights.

The entire project was manly about investigating ATK points with better data quality. The investigation of ATK units which deliver poorer data sets, such as Losna could be a very interesting approach for further research within the ATK/ WIM topic. So far were no long run data sets of Losna investigated. One of the reasons for the poor performance of the ATK unit is probably the uneven road segment in front of the unit.

7.6 ATK Storsandtunnel

The ATK point Storsandtunnel is located in Trøndelag around 30 km west of Trondheim along the motorway E39 in east going direction. Figure 16 gives an overview over the location of the ATK point. The ATK point was evaluated by using the developed data quality indicators and no additional field tests were conducted.

Figure 29 Location ATK Storsandtunnel

Table 26 shows the number of detected vehicles during the observed period from January to December 2016. These vehicles were used to calculate the raw data set a for further investigation.

Table 26 Vehicles Storsandtunnelen 2016

Axle configuration	Storsandtunnel
Detected vehicles	1 436 097
2 axle vehicles	1 310 661
6 axle vehicles	26 255
6 axle semi-trailers	17 297

Axle statistics of vehicles at Storsandtunnel are presented in Table 27, Table 28 and Table 29. Table 27 gives an overview over the total amount of axles per truck and vehicle. Every vehicle, heavier then 3,5t is categorized as a heavy vehicle / truck. Table 27 compares these shares with the length-based classification system DataInn, which is used on many Norwegian roads.

Table 27 Axels per vehicle/truck Storsandtunnel E39

Vehicles	Axles per vehicle	Trucks	Axels	Axels per truck	% Trucks	% DataInn
1 436 097	2.18	130 221	474 364	3.72	9.0 %	12 %

Table 28 and Table 29 present the shares of vehicles / trucks with double or triple bogie axels. The double and triple bogie axels were classified based on the definition of theses axle groups from the Norwegian veglista. Table 27 gives an overview over the total amount of registered vehicles and the share of trucks. The calibrated weight data from the ATK unit was used to categorize the vehicles. As mentioned earlier, was every vehicle heavier then 3,5 tons defined as a truck in that case. The following tables describe the total and percentage amount of 2- and 3- bogie axles per truck.

Table 28 2 /3-bogie axels per truck Storsandtunnel E39

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 436 097	2.18	130 221	474 364	3.72	9.0 %	12 %

Table 29 is showing the percental share of 2- or 3-boggi axles not per truck as in Table 28 but per all registered vehicles.

Table 29 2 /3-bogie axels per vehicle Storsandtunnel E39

Vehicles	Trucks	% Trucks	2- bogie	% 2- bogie	3- bogie	% 3- bogie
1 436 097	120 888	8.42 %	83 477	5.81 %	21 637	1.51 %

Figure 30 and Figure 31 give an overview over the weight distribution of 2- and 3-boggi axles at the Storsandtunnel ATK station within the year 2016.

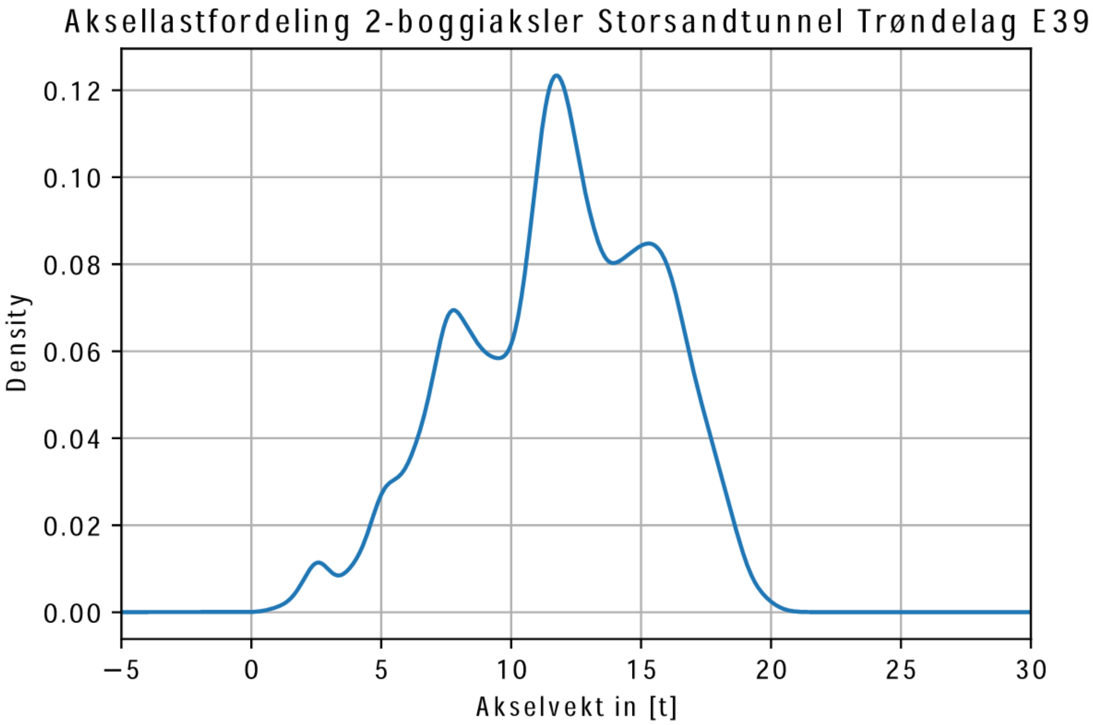

Figure 30 Weight distribution of 2-boggi axles at ATK Storsandtunnelen E39 for 2016

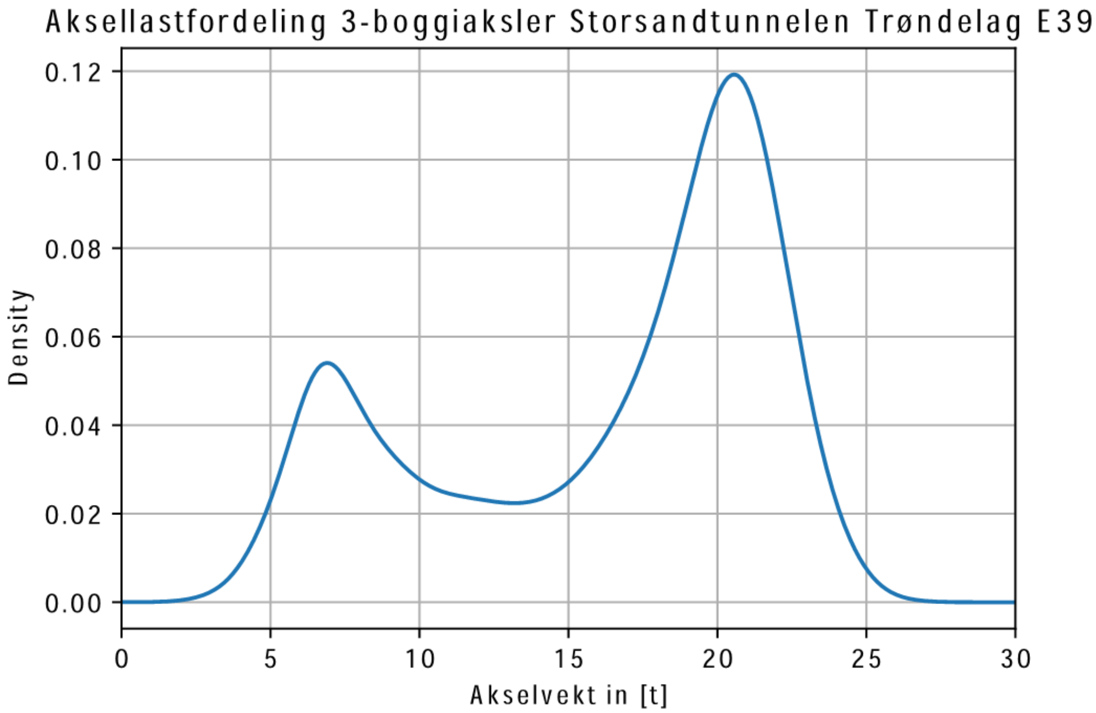

Figure 31 Weight distribution of 3-boggi axles at ATK Storsandtunnelen E39 for 2016

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Paper I
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Paper number ITS-2583, 22nd ITS World Congress, Bordeaux, France, October 2015
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Paper II
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TRA, Warsaw, Poland, April 2016
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Presented by Ass.Prof. Torbjørn Haugen, Traffic Engineering Research Centre, NTNU

Paper III
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Pedersen, T. & Haugen, T., 2017
IEEE 20th International Conference on Intelligent Transportation Systems, Yokohama, Japan, October 2017
Presented by M.Sc. Timothy Pedersen, Traffic Engineering Research Centre, NTNU

Paper IV
Analyzing the Performance of Piezoelectric Cables for Traffic and Weight Data collection on the National Road Network in Norway
European Transport Conference (ETC), Barcelona, Spain, October 2017
Böhm, M., Haugen, T., Levy, J., 2017

Paper V
Nationwide traffic and weight data collection through the innovative use of piezoelectric speed enforcement systems in Norway
Böhm, M., Haugen, T., Levy, J., 2018
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Presented by Research Scientist Maximilian Böhm, Traffic Engineering Research Centre, NTNU

Paper VI
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Böhm, M., Haugen, T., Levy, J., Brændshøi, B., 2019
ICWIM8 - 8th International Conference on Weigh-In-Motion, Prague, Czech Republic, May 2019
Presented by Ass.Prof. Torbjørn Haugen, Traffic Engineering Research Centre, NTNU

Additional presentations

Weigh in Motion data
Workshop on Traffic Management and Control, Oslo, Norway, June 2017
Presented by Ass.Prof. Torbjørn Haugen, Traffic Engineering Research Centre, NTNU

Vektdata fra ATK-punkt. Kan disse benyttes til vektstatistikk?
NADim seminar, Oslo, Norway, November 2017
Presented by Ass.Prof. Torbjørn Haugen, Traffic Engineering Research Centre, NTNU

Appendix

Comparison of average amounts of axle groups per vehicle

Table 30 Average amount of axels per vehicle and differences in categorization of vehicles between length- and weight-based categorization

ATK unit	All vehicles	Axles per vehicle	Truck	Axles	Axles per Truck	% Trucks	% Datainn
Storsand E39	1 436 097	2.18	130 221	474 364	3.72	9.0 %	12 %
Gjerdemyra E18	1 708 376	2.47	237 902	1 076 614	4.52	13.9 %	18 %
Otta Sør E6	1 430 387	2.32	203 691	846 550	4.16	14.2 %	19.0 %
Teigkamptunnelen E6 (A)	344 082	2.49	59 699	264 953	4.44	17.4 %	~ 22.6%
Teigkamptunnelen E6 (B)	338 531	2.48	57 681	256 475	4.45	17.0 %	~ 22.6%
Verdal E6 (KIST.)	2 792 707	2.21	250 511	1 038 187	4.11	9.0 %	12.7 %

Table 31 Average amount of double and triple bogie axle groups per truck at different ATK points

ATK unit	All vehicles	Trucks	% Trucks	2-boggi	% 2-boggi	3-boggi	% 3-boggi
Storsand E39	1 436 097	120 888	8.42 %	83 477	69.05 %	21 637	17.90 %
Gjerdemyra E18	1 708 369	234 125	13.70%	175 589	75.00 %	77 316	33.02 %
Auråen E18	815 496	120 974	14.83 %	89 385	73.89 %	38 517	31.84 %
Otta Sør E6	1 430 387	197 008	13.77 %	153 425	77.88 %	54 080	27.45 %
Teigkamptunnelen E6 (A)	344 082	59 209	17.21 %	47 825	80.77 %	17 961	30.33 %
Teigkamptunnelen E6 (B)	338 531	60 218	17.79 %	46 724	77.59 %	17 431	28.95 %

Table 32 Average amount of double and triple bogie axle groups per vehicle at different ATK points

ATK unit	All vehicles	Trucks	% Trucks	2-boggi	% 2-boggi	3-boggi	% 3-boggi
Storsand E39	1 436 097	120 888	8.42 %	83 477	5.81 %	21 637	1.51 %
Gjerdemyra E18	1 708 369	234 125	13.70 %	175 589	10.28 %	77 316	4.53 %
Auråen E18	815 496	120 974	14.83 %	89 385	10.96 %	38 517	4.72 %
Otta Sør E6	1 430 387	197 008	13.77 %	153 425	10.73 %	54 080	3.78 %
Teigkamptunnelen E6 (A)	344 082	59 209	17.21 %	47 825	13.90 %	17 961	5.22 %
Teigkamptunnelen E6 (B)	338 531	60 218	17.79 %	46 724	13.80 %	17 431	5.15 %

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