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INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

D1.4.10
Demonstrator:
vehicle classification based on a wayside monitoring station

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Damill AB

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Glossary

Abbreviation/acronym	Description
SP1	Subproject 1
LCC	Life Cycle Cost
TTCI	Transportation Technology Center
TPD	Truck Performance Detector
AoA	Angle of Attack
InteRRIS	Integrated Railway Remote Information Service (reg. product name)
ÖBB	Österreichische Bundes Bahn
ARGOS	Registered product name of a monitoring system
MGT	Million Gross Tonne
AC	Alternating Current
RFID	Radio Frequency Identification
SQL	Structured (Standard) Query Language
AoA	Angle of Attack
RC, X2, X11, X14	Swedish locomotive and commuter train types

1. Executive Summary

This report presents a demonstrator activity that has been part of the Innotrack SP1.

The first part of the demonstrator includes development and installation of a new wayside monitoring station on a site in Sweden. The station monitor forces, vehicle identity and steering behaviour from each passing train and presents it on-line, accessible from the Internet. After the installation has been made, data has been collected for different train types.

The second part of the demonstrator activity is a suggested innovative approach to vehicle classification based on monitored data. From post-processing of the collected data relative magnitudes of the vehicle impact on the track are calculated. One example of output is presented in figure 1.1.

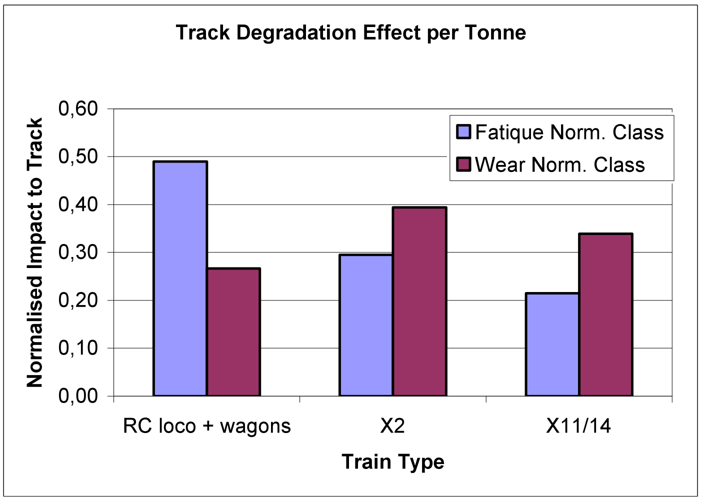

Figure 1.1: An example on how different trains are supposed to consume the track life. Numbers are normalised making theire sum equal to 1. (copy of figure 6.2).

The analysis presented in this report is partly theoretical. It can be further refined and verified by more detailed research efforts.

2. Introduction

In the Innotrack project there is a goal to find and evaluate new innovations that reduce the track maintenance costs. The quantification of decreased costs is carried out by calculations including both mechanical simulations (e.g. vehicle dynamic simulations) and economic simulations (e.g. LCC analyses). The calculation can be made with different resolutions but whatever the resolution is, there is always a need to objectively define the impact from the vehicle operations on the track. We want to do a **vehicle classification**. One scenario is when two track segments with different traffic volume are to be compared. Another scenario is when the same segment is studied over a long time during which the traffic volume and/or traffic mix has changed.

As already described in another of the SP1 reports, there are several commercial tools for doing dynamic simulation of vehicles. The tools will evaluate wheel–rail forces and the steering behaviour of the vehicles based on design data of the vehicles and geometric data for the track. As an input, they need to know mechanical parameters such as mass, clearances, stiffness, damping, wheel profiles, rail profiles, friction coefficients etc. That kind of information is not easily obtained, as vehicle designers often have no interest in revealing details of their designs. Further, complexity is added when the maintenance condition is taken into account. All these parameters makes **theoretical vehicle classifications based on simulations** both tedious and uncertain.

A powerful alternative or complement is to make an **empiric vehicle classification,** i.e. using measuring systems in the track. Measuring forces from all wheels/axles/trains for several weeks makes the statistic input very good. One drawback is of course that such data can only be available in a few specific places along the line. Consequently the full influence of the track on the vehicle is not obtained. If such data is deemed to be important, a mix of modelling and measurements can be optimal. A theoretic vehicle model can further be tuned by using the measured data.

To exemplify how track forces are influenced by the vehicle maintenance condition there are some interesting observations that can be mentioned. The monitoring system presented here has shown that worn wheels (still within in safety limits) can generate lateral forces as high as 4 times the nominal level. The same, or even higher, amplification factors can occur in the vertical direction due to local wheel defects that not necessarily exceed any safety limit.

This report presents the Vehicle Classification Demonstrator, which has been developed, installed and put into service as a part of Innotrack SP1. It s a wayside force measuring station installed on the Western Main Line near Gothenburg in Sweden. The installation was done in May 2009 and the station has been active for 7 months.

3. Similar Systems

The demonstrator system presented in this report is not unique in its technical design. There are similar systems available and operational around the world. The innovation here is the use of collected data for vehicle classification and to make a relative rank of the vehicles. The results are possible to use as input data in track degradation models or in a differentiated freight charge calculations.

Other systems available have so far been used to measure total tonnage and axle load distributions and to monitor the vehicle maintenance conditions. As they generate the same kind of base information, they can be used as alternative inputs for the analysis presented here. The following text describes two of them briefly.

3.1 TPD from Salient and Progressive Rail Technologies

In the mid 1990'ies, the Transportation Technology Center (TTCI) in U.S. developed a system called Truck Performance Detector (TPD). By mounting strain gauges on the rail and connecting them to a monitoring system it was possible to measure both vertical and lateral forces from each passing axle. Later on, also the angle-of-attack (AoA) was calculated from measured data. This concept is today a standard product with at least 22 installations in North America. They are part of the countrywide InteRRIS information system for rolling stock in U.S. Such systems installations can be bought from companies such as Salient (Internet ref: http://www.salientsystems.com/prod_tpd.html) and Progressive Rail Technologies (Internet ref: http://prt-inc.net/php/tpdServ.php). The recommended solution is to place the system in an S-shaped track section with sensors in the left curve, on tangent track and in the right curve. The triple position measurement gives a good overview of the vehicle steering behaviour.

3.2 The ARGOS system

In Europe, the Austrian ÖBB and some of their suppliers developed a system named ARGOS in 1998. The system has since then been further developed and is today in use with several installations in Austria, see figure 3.1 . It is commercially available in four levels of complexity (Internet ref: http://argos-systems.eu/wp-content/uploads/2007/06/argos_4-seiter_en.pdf). The level 3 system gives a function close to the one presented in this Demonstrator. Figure 3.2 shows some output from the Austrian system.

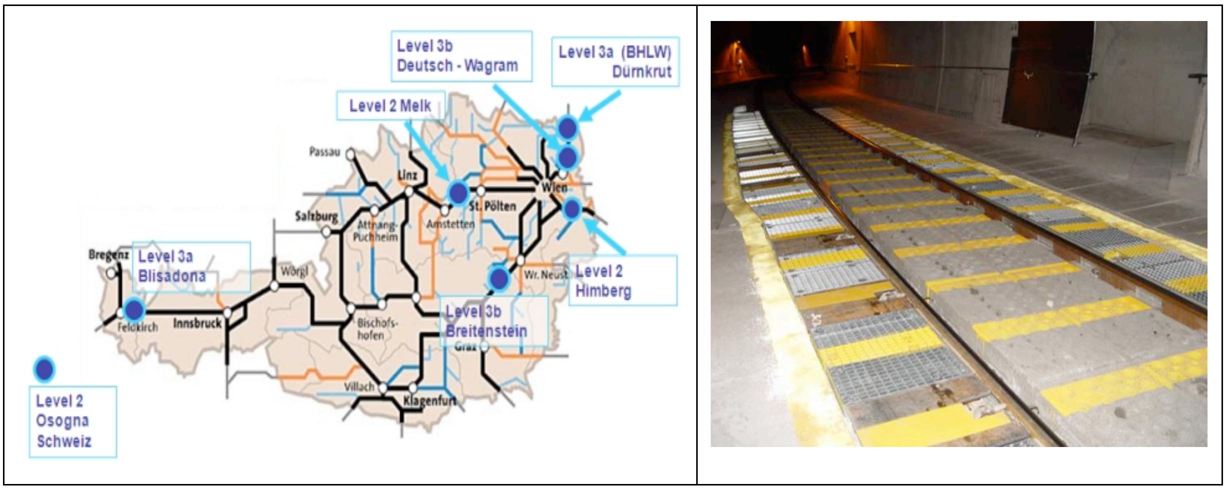

Figure 3.1: Measurements sites Level 3 ARGOS locations in Austria. The photo shows the instrumented curve in Blisadona.

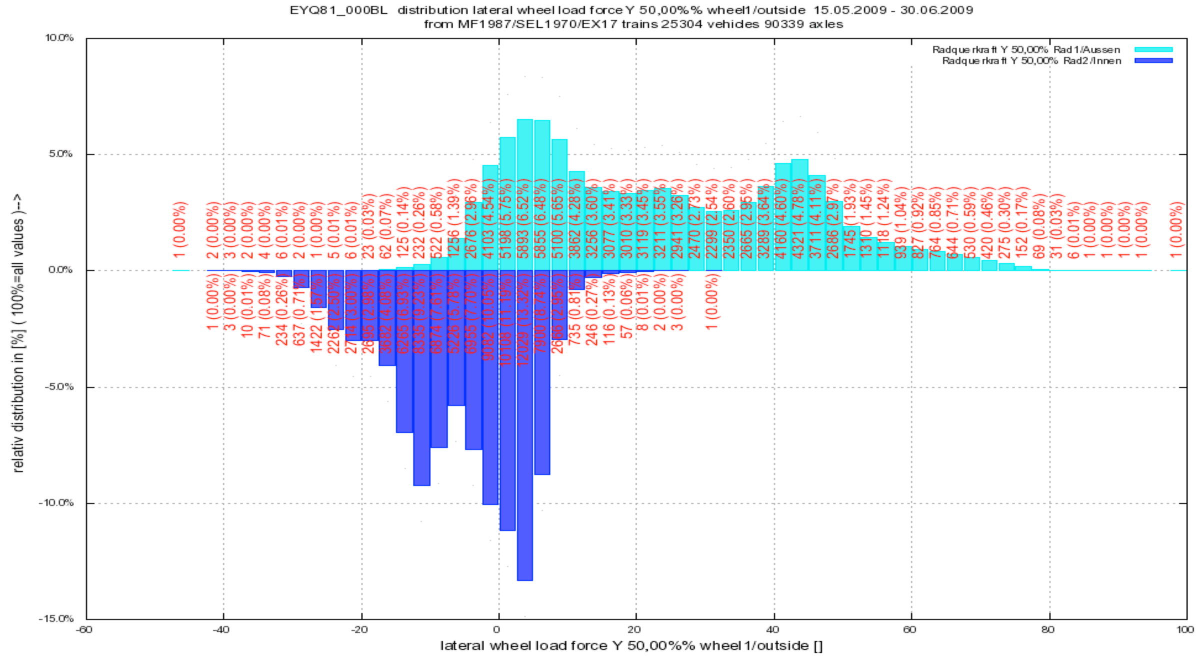

Figure 3.2: Lateral steady-state wheel forces load collective from a curve with radius 280 m (Blisadona). The X-axis shows the 50% percentile of the lateral wheel force and the Y-axis shows the relative frequency (absolute values) with 100% =90339 axles. Text in the figure with red color shows absolute and relative values of distribution

4. The Demonstrator Site

4.1 Geographic Position

The Demonstrator system has been installed in Norsesund along the Western Main Line between Stockholm-Gothenburg, see figure 4.1. This is a suitable place for a demonstrator due to the mixed and quite intensive traffic at the location.

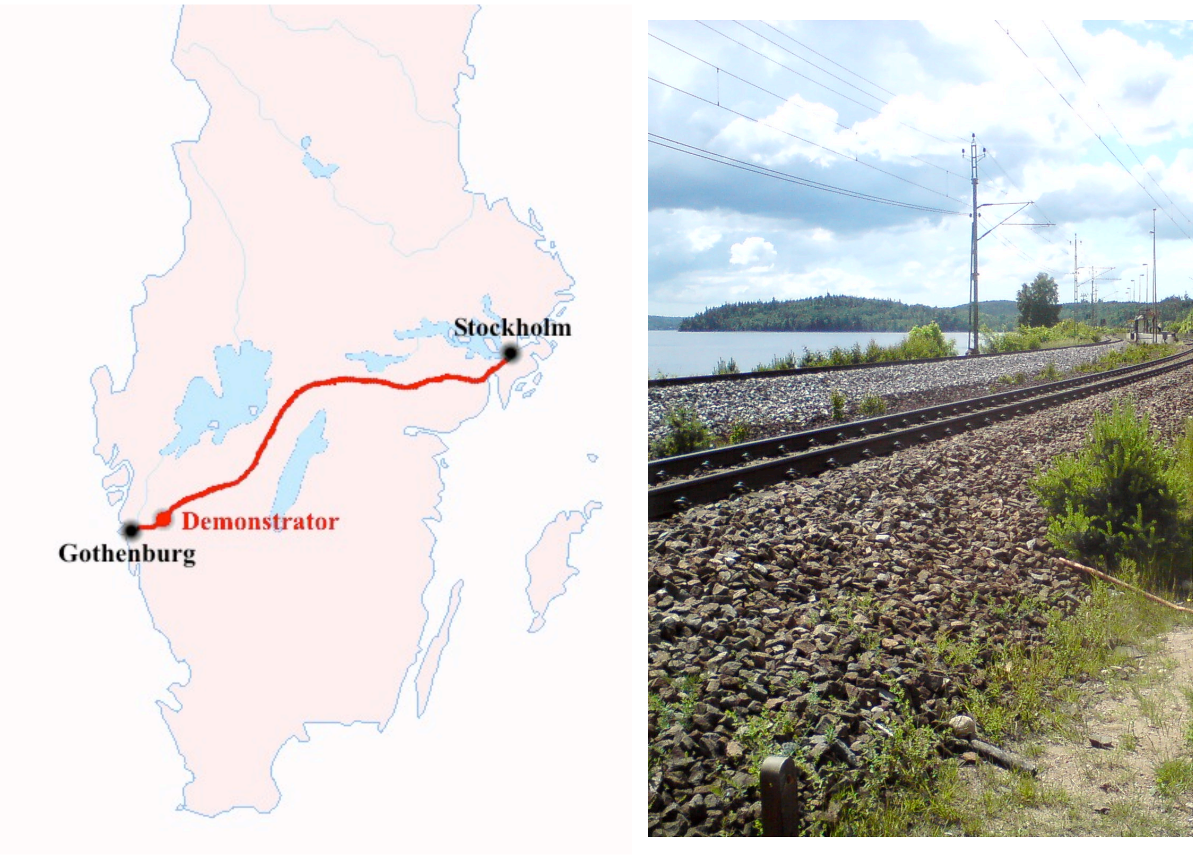

Figure 4.1 The Demonstrator location in Norsesund marked with a red dot. The photo shows the instrumented curve.

4.2 Site Data

Track position:	km 422+530, pole 422-13
Cant:	150 mm
Gradient:	-0,2%
Rail:	SJ 50
Fasteners:	Hambo
Sleepers:	Concrete
Transportation:	Passenger and freight
Curve Radius:	-589 m (left)
Double track:	Yes. Only the left track, with mainly westbound traffic, is instrumented .

Tonnage: approx 10 MGT/year

Vehicle Types: The X2 high-speed trains carry the long distance passenger traffic between Stockholm and Gothenburg. Regional trains run on several routes around Gothenburg: Regional passenger traffic mainly consists of Regina Motor Cars of type X53 operated by SJ. Other regional trains use the X14 or the Diesel Multiple Units of type Y1 and Y31. The local commuter train uses the X11 type railcars. Freight trains are running largely at night due to the intense passenger traffic. Freight transport is dominated by the operator Green Cargo using locomotives type RC2 and RC4. RC3 locomotive are faster and used in mail transport trains between Stockholm and Gothenburg. Besides the electrical locomotives there are also diesel locomotives in use for freight trains. Locomotive types such as TMX, TMY and TMZ can therefore also be seen on the Western main line.

5. The Demonstrator

The Monitoring station is developed and delivered by Damill AB. The system consists of a cabinet with computer, sensor electronics and communication equipment inside. In track there is a special type of strain gauges mounted onto the rail web. The installation does not require any changes in the track superstructure reducing installation time and cost. During the period June 1 – December 31, 2009 the Demonstrator station has scanned more than 10 000 trains.

5.1 Installation

The installation was made in May 2009. A cabinet (figure 5.1-5.2) was placed close to the track and 230V AC power supply was brought from the nearby railroad crossing. In the far (westbound) track a set of strain gauge sensors (figure 5.3) were mounted onto the rails. The sensor cables were buried in the ballast and connected at the cabinet. As only a few cables for powering and sensor signals were needed, the installation and electrical commissioning was made in less than 24 hours. The needed traffic downtime was 3 hours split into 15-minute time slots. After installation the station delivers data to the Internet via a wireless radio link (figure 5.4). The same link is used for remote supervision of the station.

Figure 5.1: Cabinet in place. The round hole up to the left is for the camera based train identifier.

Figure 5.2 Cabinet with open doors. Computer and sensor electronics are placed to the left while the consol is placed to the right.

Figure 5.3: Several strain gauges are mounted in a specific pattern on both rail webs. They are all fully encapsulated.

Figure 5.4: Wireless communication brings data to the Internet and facilitates remote control of the station.

5.2 Function

The station continuously evaluates stress variations in the rail via strain gauges. It starts automatically to store data when a vehicle passes. The strain gauges are placed on the rail in a pattern that makes them extremely sensitive to the wheel contact position and the load. By using fast scanning software the wheel passing time for the left and the right wheel can be evaluated, making it possible to count axles and even define the axle steering angles AoA (Angle-of-Attack). A few seconds after the passage, the post processing of data is finished and data is presented on the integrated Internet web server. In spite of the low number of sensors used, the station delivers several dynamic track stress indicators suitable for vehicle classification. By enhanced data analysis the following data can be extracted from the same sensors:

- Locomotive type
- Train speed
- Axle count
- Travelling direction
- Vertical wheel load (low and high frequency)
- Lateral wheel force (low and high frequency)
- Angle-of-attack (axle steering angle)

The locomotive type and the train speed are calculated from pattern recognition of axle pass delta-time for the first passing axles. The system can also be configured to read RFID-tags on passing vehicles. If such tags are present the measured data is sorted accordingly. Vehicle ID and measured data is then stored in an SQL database where trending can be evaluated for each vehicle. As RFID tags are not yet common, the Demonstrator station has been provided with some extra features. A camera has been added on top of the cabinet and takes a photo of passing locomotives. The photo is time-stamped and stored together with the sensor data. In later data studies the photos can be used for simple identification of the operator.

After each train passage, the systems Internet web page is updated. In standard configuration the web page presents an overview of all trains passing the current day. This includes their speed, vertical load and lateral forces.

5.3 Output

The Demonstrator web page (figure 5.5) provides a compact overview of each day.

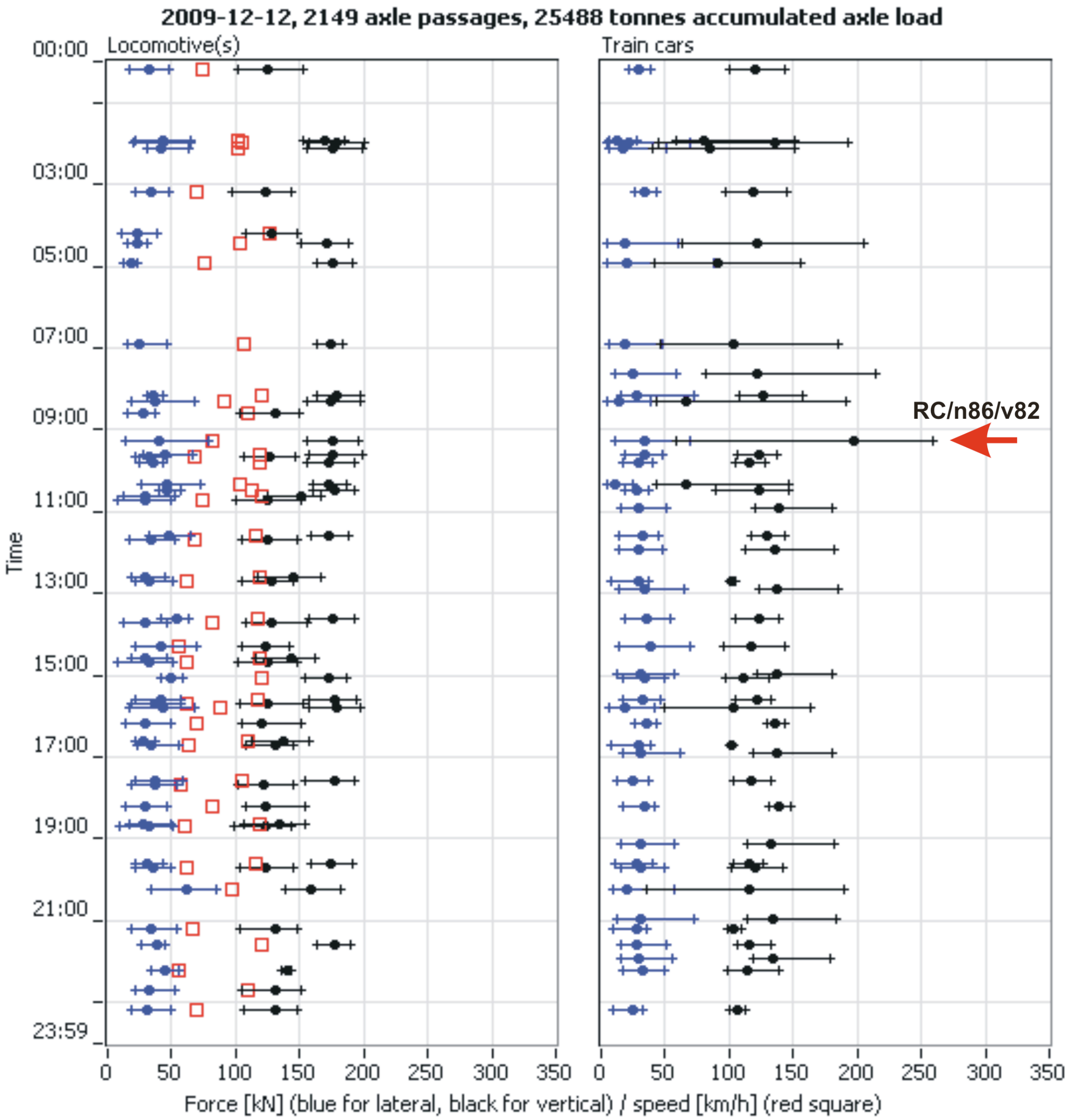

Figure 5.5: The web page shows daily data. It is updated after each train passage. Each horizontal line represents a train. Black lines shows min/mean/max of the axle loads and the blue lines shows min/mean/max of the lateral forces. There are separate diagrams for locomotives and wagons. The red rectangles indicate the train speed.

Detailed data covering each axle is not available from the web page but can be obtained from a data file stored for each train.

5.3.1 Data Examples

Detailed data for each train is well visualized by plotting each parameter versus the axle number. Figures 5.6–5.10 show some typical data from four different X2 passages. The legends indicate date and time of passage for the train studied.

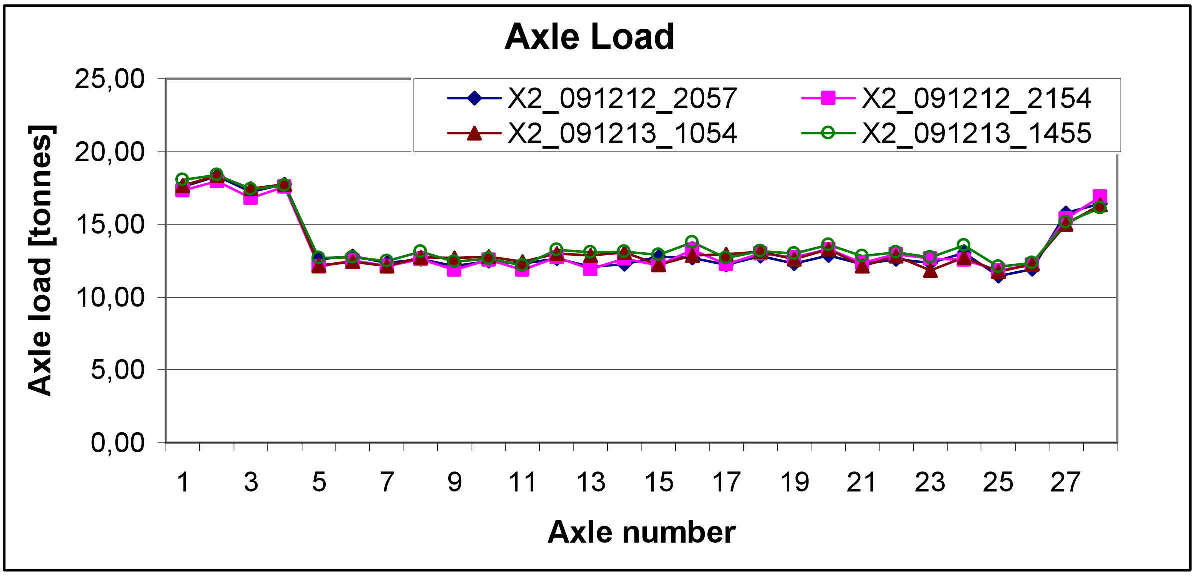

Figure 5.6: Axle load from four different X2 trains passing the station. The driving end has higher load then the rest of the train

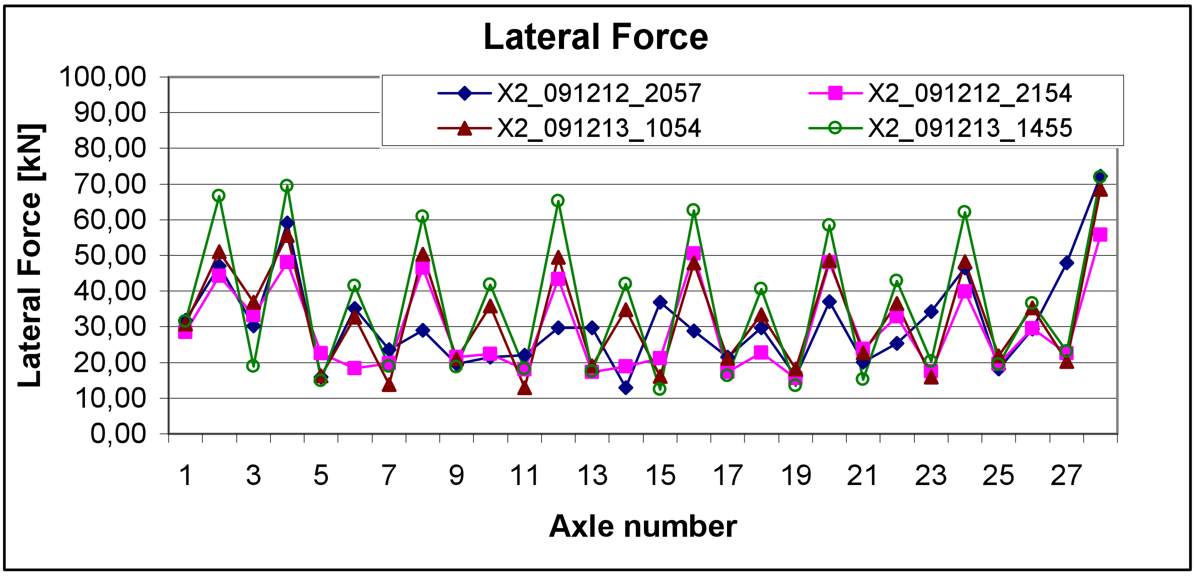

Figure 5.7: Lateral forces from the same X2 trains as in figure 5.6. This information is closely related to the steering performance of the vehicles.

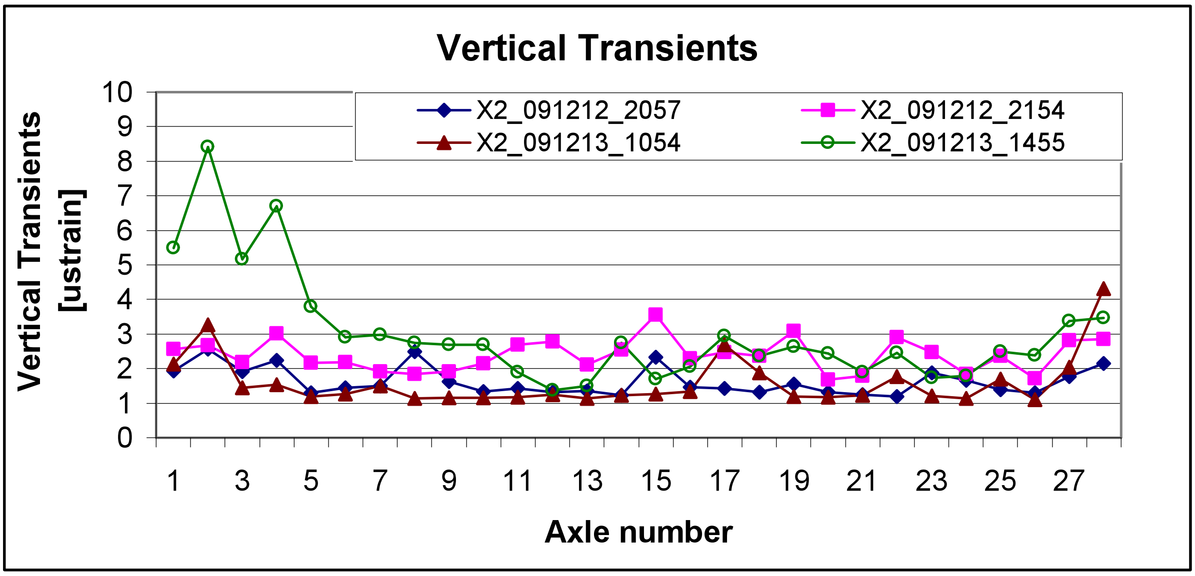

Figure 5.8: Vertical transients for the axles show high frequency vibration components from the wheel-rail interface. High unsprung mass, high mass and worn wheel surfaces add to the magnitudes.

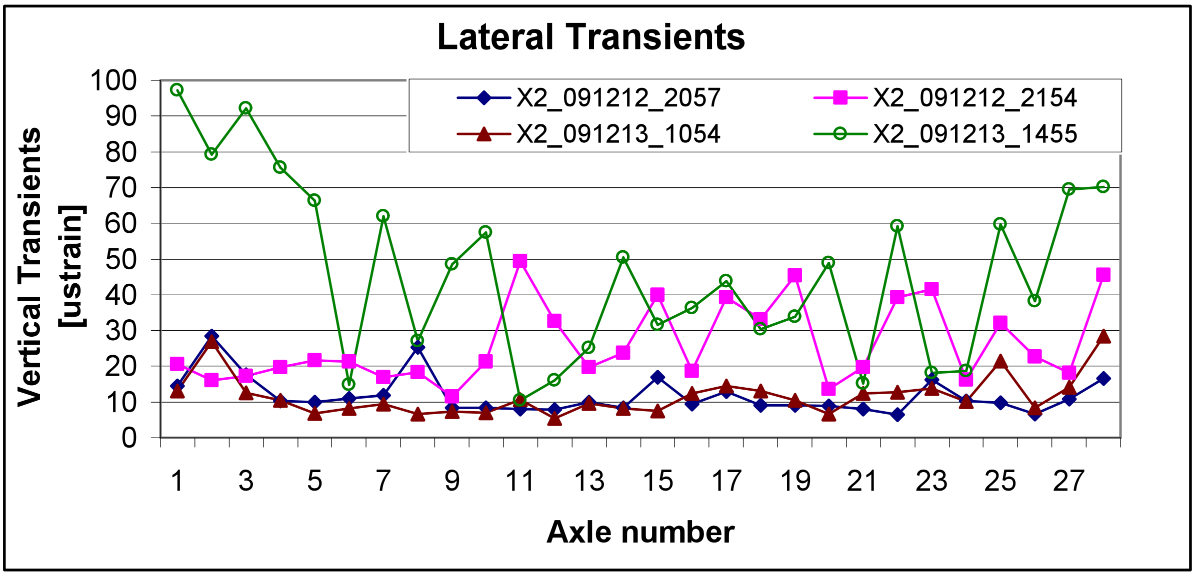

Figure 5.9: Lateral transients are similar to the vertical transients. The use of this data is still under investigation.

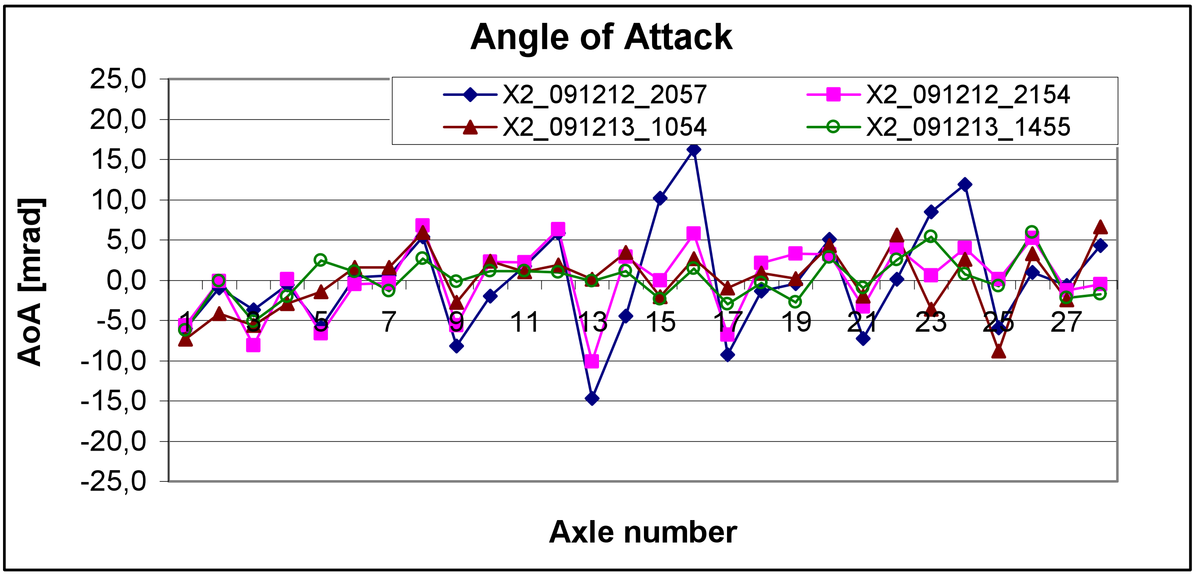

Figure 5.10: This diagram shows the Angle-Of-Attack deviation from mean value of the train. Absolute angles are theoretically possible to define from sensor data, however left and right rail can move relative to each other causing an unknown offset in the data.

6. Analysis

6.1 Track Utilization

In the daily plots on the web page both accumulated tonnage and number of axles are presented. These two numbers are the basic information for calculating the track utilization and, subsequently, the track degradation.

6.2 Vehicle Classification

Measured data such as presented in chapter 5.3.1 can be used for vehicle classification. The purpose of the classification is to rank each vehicle type with relative numbers indicating their impact on the track. The classification can be used in predictions of future maintenance needs of the track and for distributing actual maintenance costs on the different kinds of operational traffic. It would also be suitable for calculations concerning differentiated track access charges. The strength of the approach would be a method that covered both design and maintenance aspects.

According to some track degradation models, the two major cost drivers are wear and fatigue of the rail. This should accordingly influence the classification. In short, the formulas employed for each vehicle can be expressed as:

$$F = k_1 * n^b * A^3$$

$$W = k_2 * n * A \qquad \text{alt.} \qquad W = k_3 * n * A * \sin(\phi)$$

where:

F= fatigue rate

W=wear rate

k_1, k_2, k_3 = Constants (per vehicle) including vehicle properties

n= accumulated number of axles

b= exponent describing a non-linear growth rate in time. Can be set to 1 to get a linear model.

A= axle load

ϕ =Angle-of-Attack, each axles angular deviation from the ideal steering direction

As described above, the monitoring station generates data about the axle count and the axle load. It also presents data about transients, lateral forces and AoA. It is relevant to assume that the extended data set can, in fact, provide most input to the calculations above, including the *k*-factors. This chapter presents one possible but still partly hypothetical way to sort the vehicles by their impact on the track, i.e. to do a vehicle classification.

The suggested model is to use the vertical static+transient load to represent *A* in the fatigue-formulas above and to use the lateral static+transient forces to represent *A* in the wear-formulas. As the lateral forces depend on axle load, speed, effective conicity, AoA, cant and friction, they will cover most aspects. In tangent track the wear rate is low but still existing and that is also true for the measured lateral forces. The axle count *n* is directly given by the measured data.

To exemplify the results, this report shows such an approach on data from three different train types common in Norsesund. These are:

- RC-locomotives pulling freight wagons of different types
- X2 high-sped passenger train
- X11 commuter trains

By taking mean values of passages for each train type at four different occasions, the data in figure 6.1 was obtained.

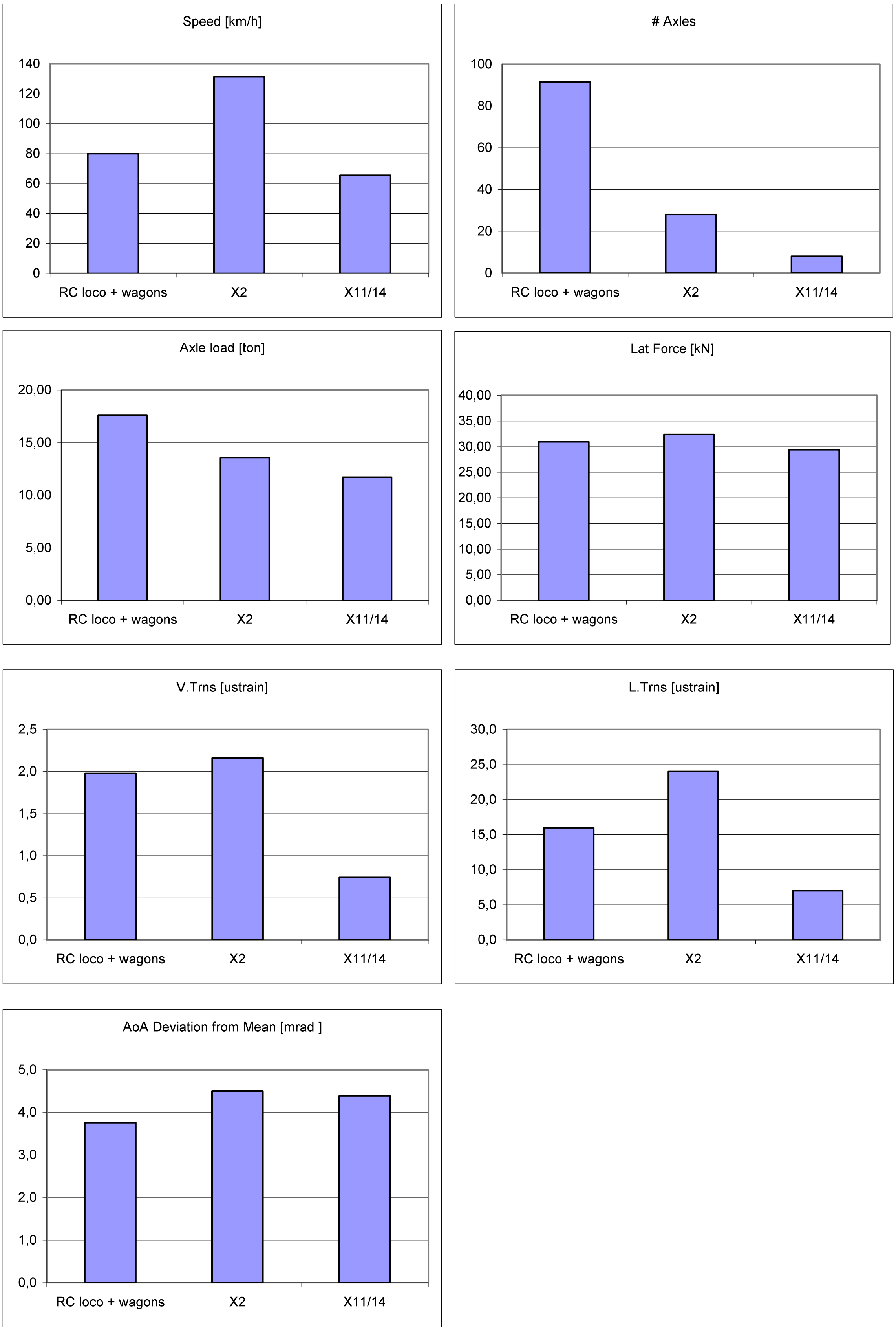

Figure 6.1: Examples of data from Norsesund. Each bar corresponds to the mean value of four train passages of the pertinent train type.

The diagrams in figure 6.1 contain a lot of information but it is difficult to get an overview. The information is in the next step of analysis introduced into the model described on page 16. The vehicle types are assigned relative numbers k_5- k_7 and k_9- k_{11} ranking their impact on the track (superposition of data from different vehicles is expected to be valid):

$$F = k_4 * (k_5 * RC + k_6 * X2 + k_7 * X11)$$
$$W = k_8 * (k_9 * RC + k_{10} * X2 + k_{11} * X11)$$
$$k_5 = normalised(n * (A_{RCstat} + A_{RCtrns})^3)$$
$$k_6 = normalised(n * (A_{X2stat} + A_{X2trns})^3)$$
$$k_7 = normalised(n * (A_{X11stat} + A_{X11trns})^3)$$
$$k_5 + k_6 + k_7 = 1$$
$$k_9 = normalised(n * (L_{RCstat} + L_{RCtrns}))$$
$$k_9 + k_{10} + k_{11} = 1$$

where:

$$F = fatigue\ rate\ in\ track\ due\ to\ trains\ RC + X2 + X11$$
$$W = wear\ rate\ in\ track\ due\ to\ trains\ RC + X2 + X11$$
$$k_{4,8} = track\ dependent\ coefficients$$

The calculation of normalised coefficients k_5- k_7 and k_9- k_{11} can be done either on a per train bases or on a per tonne basis. Employing both alternatives results in the numbers presented in table 6.1 and graphically in figure 6.2.

Classification per train

Vehicle Type	Fatique Norm. Class	Wear Norm. Class
RC loco + wagons	0,86	0,70
X2	0,12	0,25
X11/14	0,02	0,05

Classification per tonne

Vehicle Type	Fatique Norm. Class	Wear Norm. Class
RC loco + wagons	0,49	0,27
X2	0,30	0,39
X11/14	0,21	0,34

Table 6.1: A relative ranking of the vehicle types RC, X2 and X11 based on measured data from Norsesund. Data are normalised so that the sum of each column is 1 (=100%)

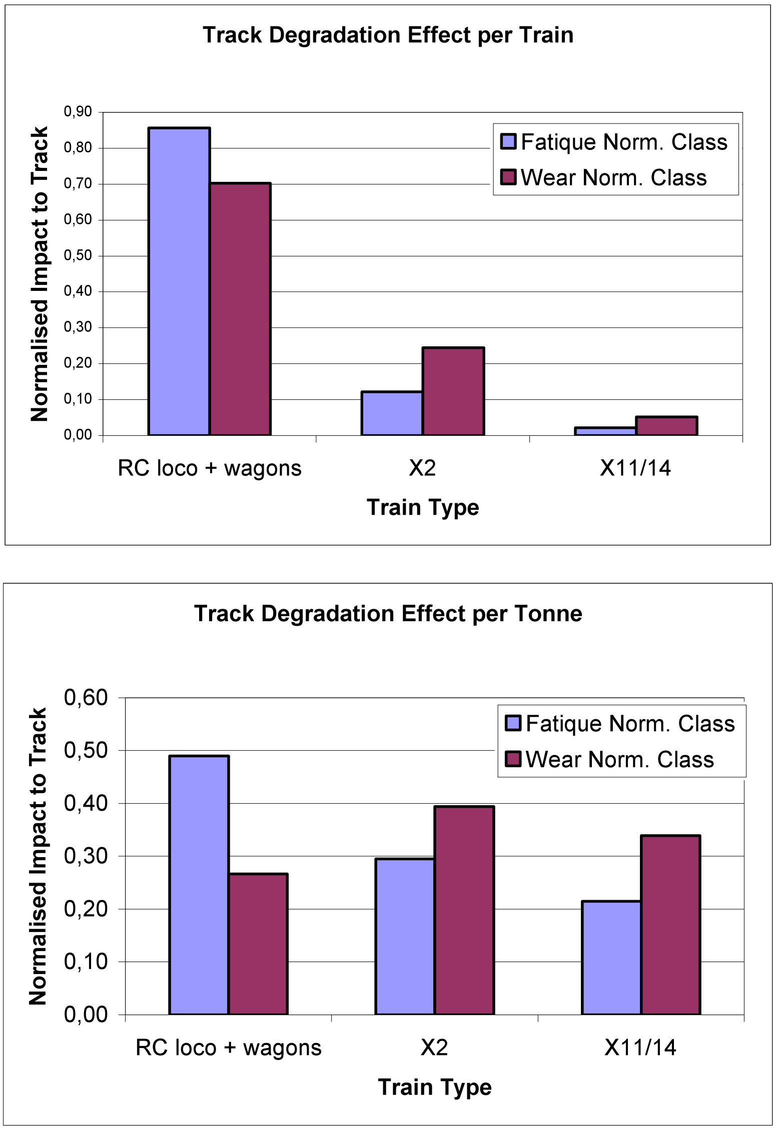

Figure 6.2: Numbers from table 6.1 plotted in bar diagrams.

The results indicate that a loaded freight train of the type and size that is common in Norsesund will generate 7 times more fatigue and 3 times more wear as compared to a faster but lighter X2 passenger train. Axle load, number of axles, vehicle dynamic impact and steering performance are all included in the evaluation.

Changing to a per tonne basis makes the impacts more similar. A loaded freight train will generate 1,6 times more fatigue but only 0,7 times of the wear as compared to the X2 passenger train. This is not so surprising since the fast trains generate more dynamic and quasi-static forces and the yaw stiffness needed for fast trains will contribute to increased lateral force magnitudes.

The formulas and calculations presented here are as mentioned earlier partly hypothetical and can be further refined by more research. Still, the data from the Demonstrator is without a doubt a potential source to vehicle studies and classifications where not only the design but also the maintenance condition is highlighted.

7. Conclusions

This report presents an enhanced wayside monitoring station that generates several performance indicators for passing vehicles. By using modern technology in the mechanical installation, in the computer system and in the communication interface, the installation is very compact and easy to maintain.

A potential use of the system is to make vehicle classifications based on measured real time data. The report shows that most of the available output from the system is relevant as a basis for an empirical approach to vehicle classification. The examples given here for three different train types have been manually calculated and the results give one example on how data can be used.