Axle loads; Equivalent Axles or Load Spectrum?

Joint Nordic/Baltic Symposium on Pavement Design and Performance Indicators

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ESAL; Equivalent Single Axle Loads

- **One of the main deliverables of the AASHO Roads Test 1958 – 1960**
- **A method of aggregating all traffic loads into their equivalent number of standard single axle loads.**
  - **Single axle**
  - **18 000 lbs (18 kips) axle load**
  - **Dual tyre**
- **Widely used in many countries for many years**
- **LEF: Load Equivalency Factor**
- **EDF: Equivalent Damage factor**
- **(ESWL: Equivalent Single Wheel Load)**

The original AASHO Equations

$$LEF = \frac{W_x}{W_{18}} = \left(\frac{L_{18} + L_{2S}}{L_X + L_{2X}} \right)^{4,79} \times \left(\frac{10^{G/\beta_X}}{10^{G/\beta_{18}}} \right) \times \left(L_{2X} \right)^{4,33}$$

$$G = \log\left(\frac{4,2 - p_t}{4,2 - 1,5} \right) \qquad \beta_X = 0,3 + \left(\frac{0,081 \times \left(L_X + L_{2X} \right)^{3,23}}{\left(SN + 1 \right)^{5,19} \times L_{2X}^{3,23}} \right)$$

where: L_X = the axle load (lbs)

L_{2X} = code for axle configuration

Single axle:	$L_{2X} = 1$
Tandem axles:	$L_{2X} = 2$
Triple axles:	$L_{2X} = 3$ (from 1986)

SN = structural number of the pavement

p_t = terminal serviceability index

Original LEF is a function of:

- **the axle load**
- **the axle configuration**
- **the structural number of the pavement**
- **the terminal serviceability index**

The LEF equation is since 1960-ies presented in many variants

The most simplified version:

the fourth power law

$$LEF = \left(\frac{W_X}{18} \right)^4$$

Not very useful because:

applicable only to single axles with dual tyres, based on serviceability index as the performance parameter

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Minnesota: the MnRoad Project

The Serviceability Model

$$EDF = \left(\frac{FA}{18 \times 0{,}552}\right)^{4{,}15} + m_1 \times \left(\frac{SA}{18}\right)^{4{,}15} + m_2 \times \left(\frac{TA}{18 \times 1{,}85}\right)^{4{,}15}$$

The Roughness (IRI) Model

$$EDF = \left(\frac{FA}{18 \times 0{,}523}\right)^{3{,}85} + m_1 \times \left(\frac{SA}{18}\right)^{3{,}85} + m_2 \times \left(\frac{TA}{18 \times 1{,}85}\right)^{3{,}85}$$

EDF = equivalent damage factor (per vehicle)
FA =front axle load, single axle, single tyre (lbs)
SA = single axle load, dual tyre (lbs)
TA = tandem axle load, dual tyre (lbs)
m_1 = no of single axles per vehicle (front axle excluded)
m_2 = no of tandem axles per vehicle (dual tyres)

The exponent:

Minnesota, Mn Road

Serviceability index: **exponent = 4,15**

Roughness index, IRI: **exponent = 3,85**

Increase in rutting: **exponent = 2,98 (single axles)**

exponent = 3,89 (tandem axles)

Cantebury, New Zealand:

27 mm asphalt surface om 275 mm granular base course.

Pavement deterioration based on rutting:

Exponent varied from 3 to 9

- **7th International Symposium on Heavy Vehicle Weights & Dimensions,Delft, The Netherlands, Europe, 2002**

Distress and damage factors for flexible pavements,

Norwegian Public Roads Administration, publication no 66

$$LEF = k_{at} \times k_{wt} \times k_{ld} \times k_{tp} \times \left(\frac{P}{P_0} \right)^{\alpha}$$

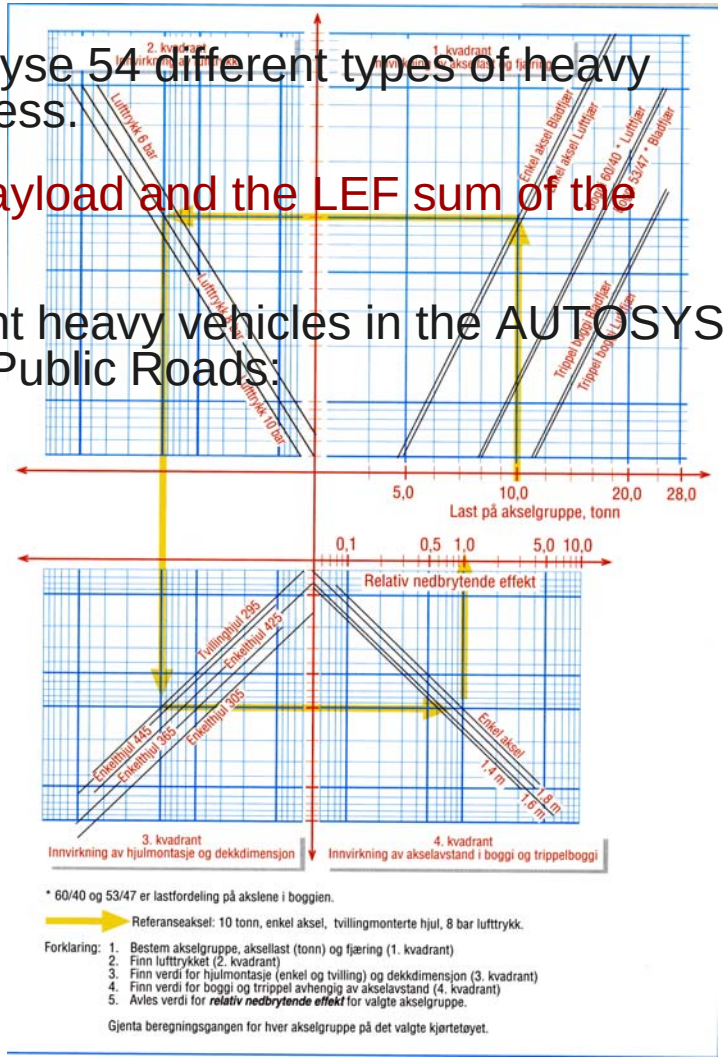
k_{at}	expresses the effect of axle type, including the axle spacing
k_{wt}	expresses the effect of wheel type (single vs dual tyres, wide base, etc)
k_{ld}	expresses the effect of suspension system (leaf spring or air)
k_{tp}	expresses the effect of tyre inflation pressure
P	the load on one axle (each axles in tandem or triple axle configuration are looked at separately)
P_0	the reference load on one single axle
α	the exponent (value depends on the type of distress)
	fatigue cracking: α = 2,0
	roughness: α = 4,0

Norwegian Public Roads Administration 1990 – 94:
Better utilization of the bearing capacity of the roads" (BUAB).

- A subtask of the BUAB project was to analyse 54 different types of heavy vehicles with respect to their road friendliness.
- Road friendliness: the ratio between the payload and the LEF sum of the vehicle.
- The types of vehicles in the study represent heavy vehicles in the AUTOSYS database of the Norwegian Directorate of Public Roads:
  - 5 busses
  - 8 trucks
  - 13 semitrailers
  - 28 full trailers

Mest vegvennlige vogntog	Relativ nedbryt-ende effekt	Veg-vennlig-het
Slepevogn	2,5	12,8
Semitrailer	2,4	12,6
Slepevogn	3,1	10,8

Minst vegvennlige vogntog	Relativ nedbrytende effekt	Veg-vennlig-het
Påhengsvogn	6,2	5,4
Semitrailer	5,4	5,9
Slepevogn	4,9	6,8



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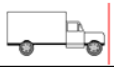
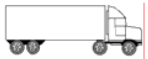
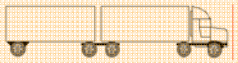
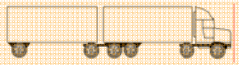
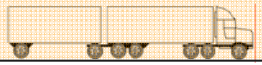
Load spectra

- **ME-PDG (AASHTO 2002 Design Guide)**

- **Quite complex, requires a lot of data**
  - **Vehicle class distribution (10 heavy vehicle classes)**
  - **Axle load distribution single axles for each vehicle class**
  - **Axle load distribution, tandem axles for each vehicle class**
  - **Axle load distribution, triple axles for each vehicle class**
  - **Average number of single axles per vehicle (for each vehicle class)**
  - **Average number of tandem axles per vehicle (for each vehicle class)**
  - **Average number of triple axles per vehicle (for each vehicle class)**
  - **Tyre pressure, distance between axles, etc. etc.**

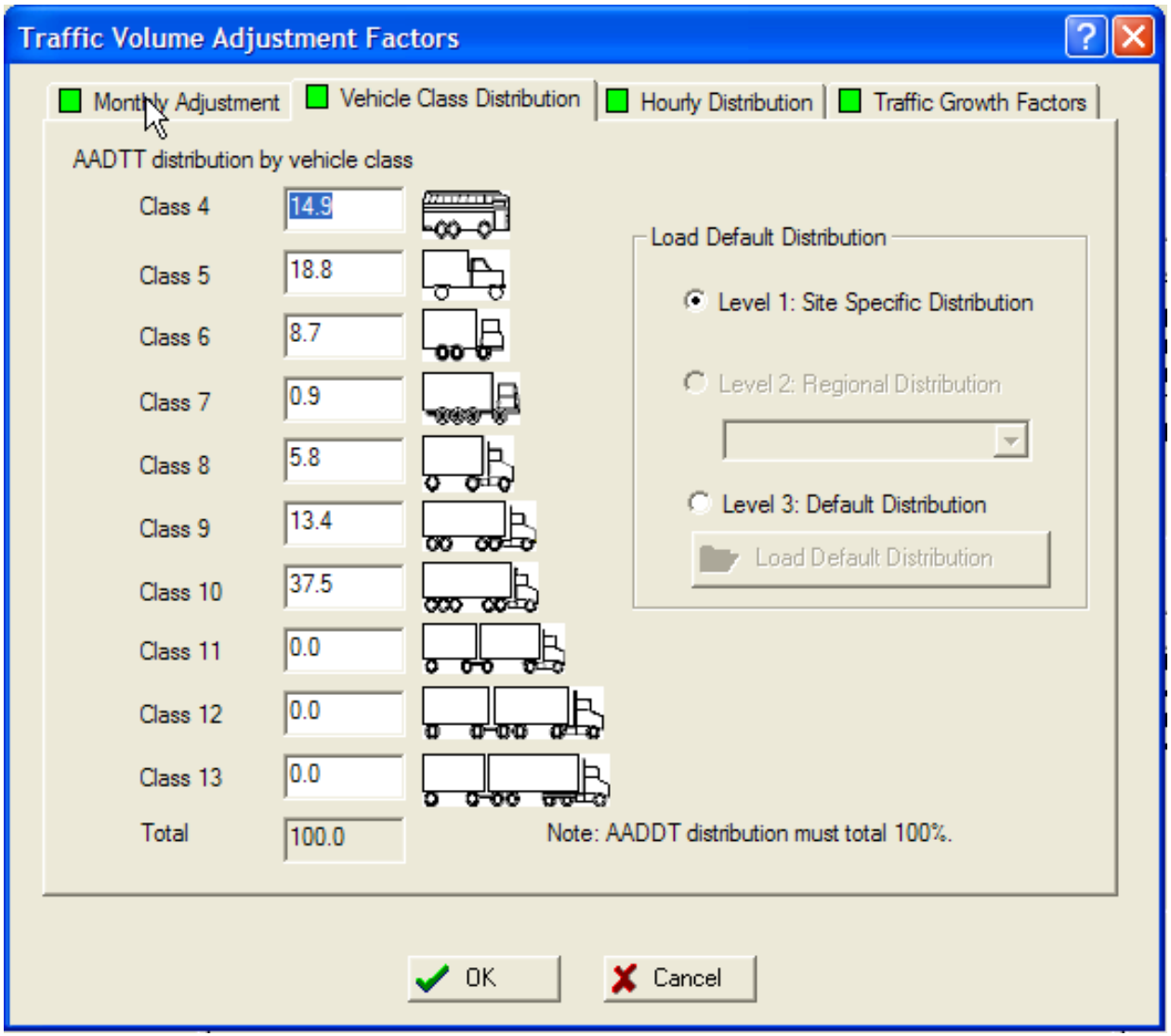
The FHWA classification is not fully comparable with the European truck and trailer combinations

Table 1. FHWA commercial vehicle classification schema.

Vehicle Class	Schema	Description
4		Buses
5		Two-axle, six-tire, single-unit trucks
6		Three-axle single-unit trucks
7		Four- or more than four-axle single-unit trucks
8		Four- or less than four-axle single trailer trucks
9		Five-axle single trailer trucks
10		Six- or more than six-axle single trailer trucks
11		Five- or less than five-axle multi-trailer trucks
12		Six-axle multi-trailer trucks
13		Seven- or more than seven-axle multi-trailer trucks

The BWIM classification: truck and trailer combinations are included in the 8 – 10 FHWA classes

FHWA Vehicle Classification



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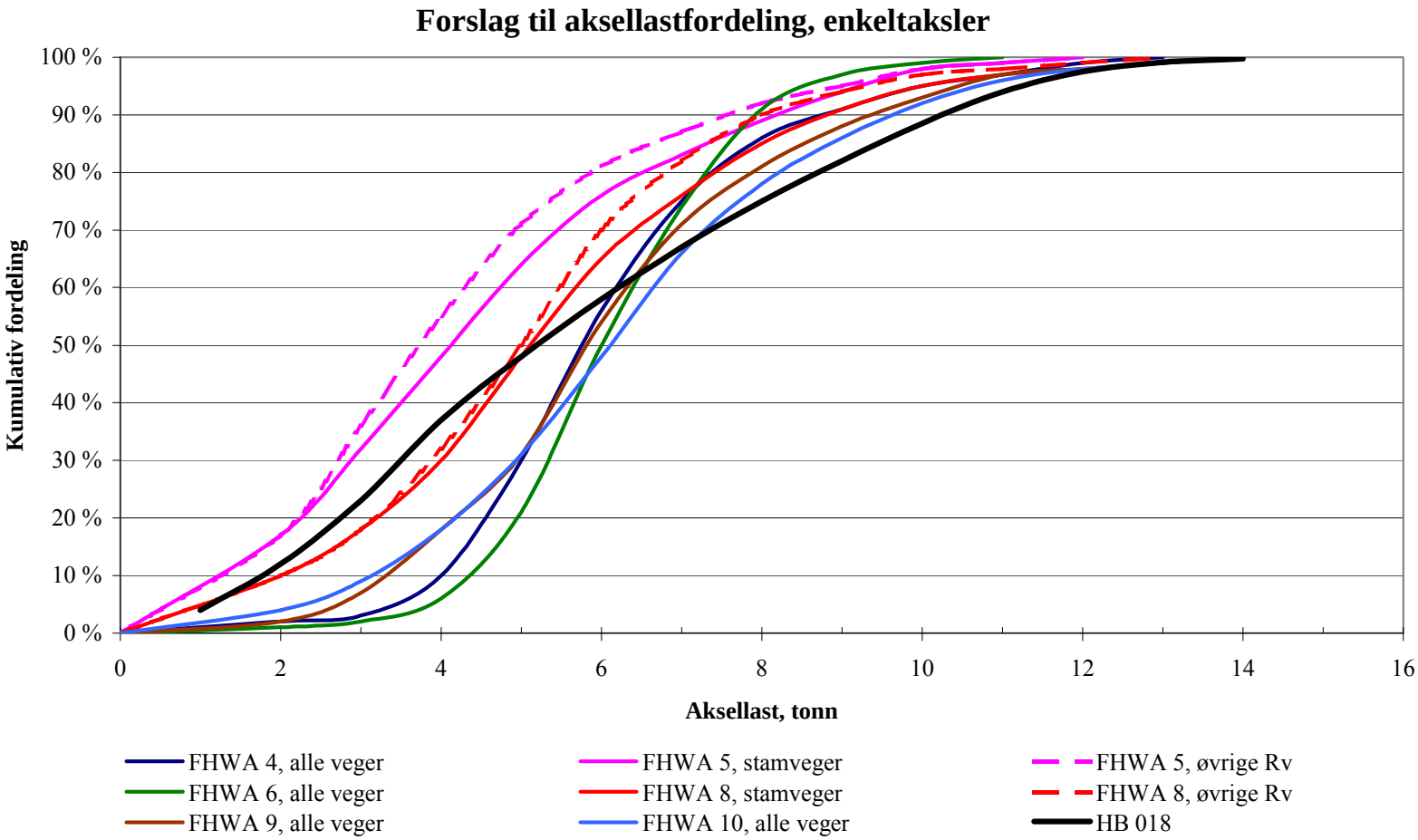
Average number of axles per vehicle

Number Axles/Truck | Axle Configuration | Wheelbase

	Single	Tandem	Tridem	Quad
Class 4	1.69	0.33	0	0
Class 5	2	0	0	0
Class 6	1.01	0.99	0	0
Class 7	1.48	0.75	0.34	0
Class 8	3.01	0.37	0	0
Class 9	2.48	0.41	0.57	0
Class 10	2.27	1.52	0.17	0
Class 11	4.29	0.26	0.06	0
Class 12	3.52	1.14	0.06	0
Class 13	2.15	2.13	0.35	0

Axle load distribution, single axles



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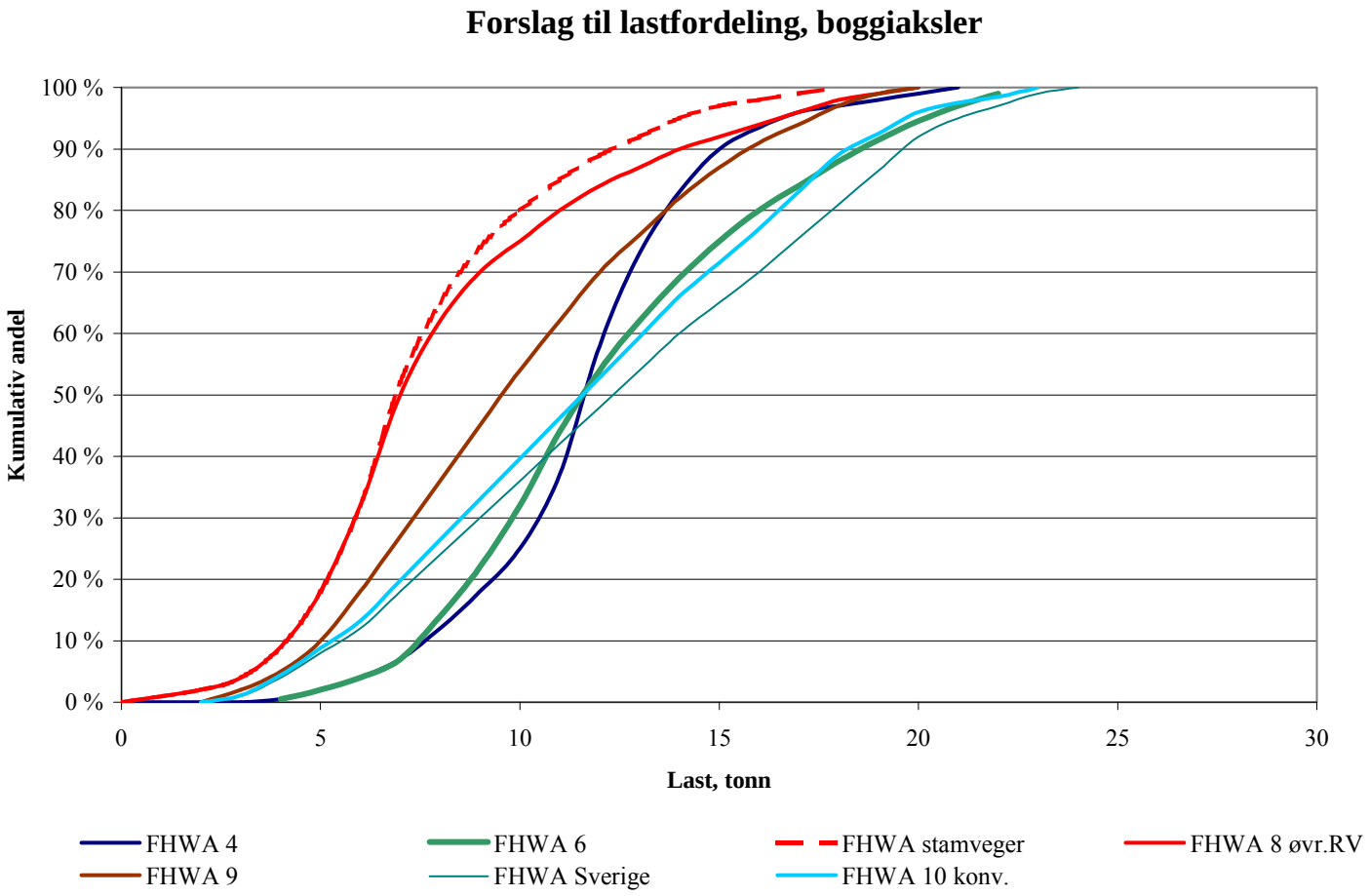
Axle load distribution, tandem axles



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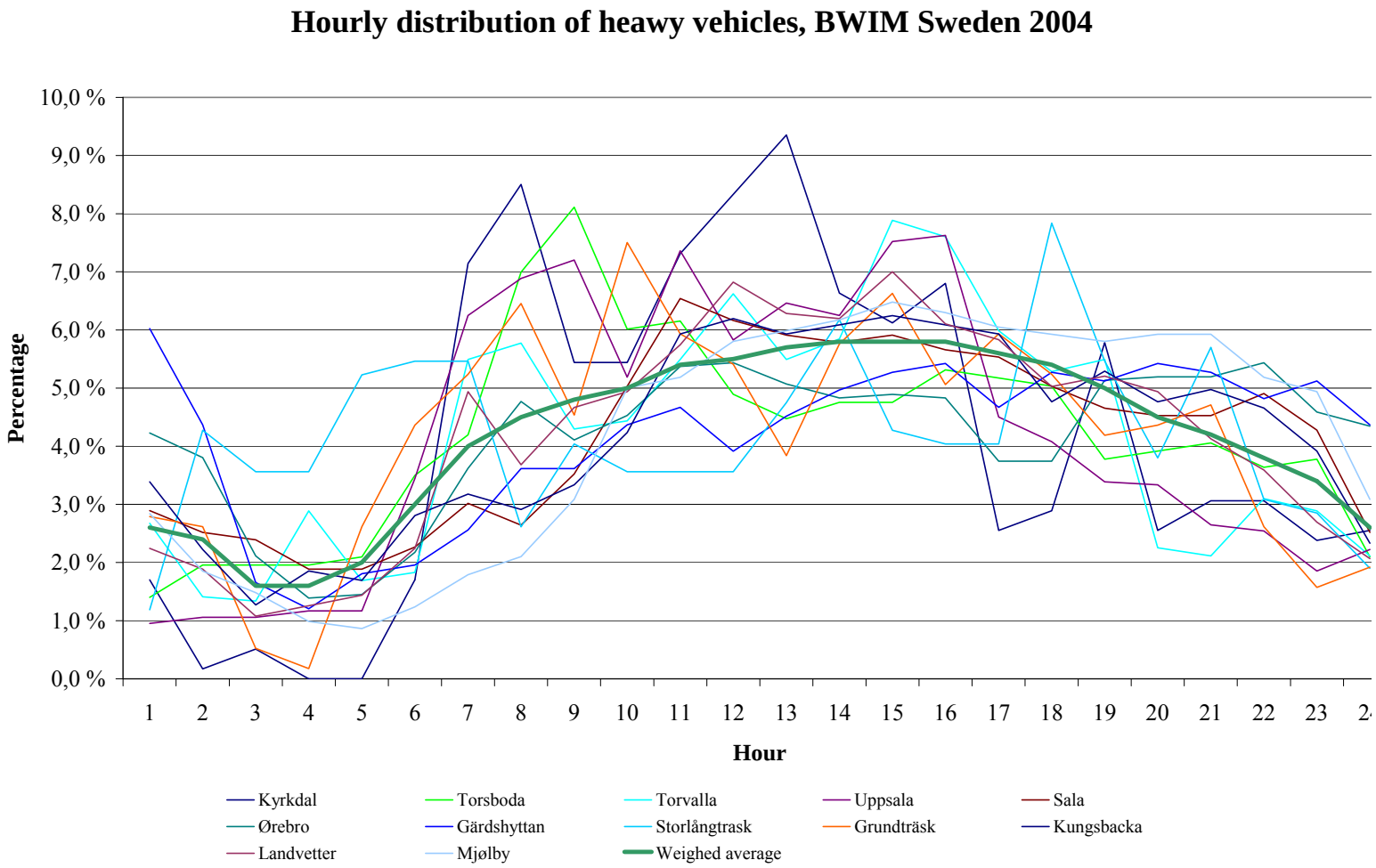
Hourly distribution of heavy vehicles, Sweden



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Equivalent Axles or Load Spectrum?

- **In the short term:**
  - **All pavement design systems have some calibration against pavement service lives or observed pavement deterioration.**
  - **A lot of experience is connected to ESWL. Even ME-PDG presents ESWL in design project (temporary text files) as information.**
  - **In pavement design the expected future traffic loads should be based on the same principles that were used for calibration.**

If you get the correct results from wrong input data, you would most certainly get the wrong results from the correct input data!

Equivalent Axles or Load Spectrum?

- **In the long run:**

- **Use of load spectra is prefered**
  - **Load spectra require a large number of data**
  - **Equivalent axles require a large number of coefficients to give the correct results**
  - **ESWL is a relatively inaccurate simplification of the influence of traffic loads om pavement performance.**
  - **WIM and BWIM data favour the use of load spectra**
  - **Load spectra are easily adaptable to new trends in truck and trailer design as well as axle configurations**