Analysis of the WLTP in-use driving behaviour database with respect to acceleration and deceleration phases

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Description of the WLTP Database

- **The WLTP in-use driving behaviour database consists of driving behaviour data from five different regions in the world (see Table 1).**

- **The data from Europe and the major part of the US data is customer data and thus reflects the practical use of the vehicles in real traffic.**

- **The data from India, Japan and Korea is not customer data. Vehicles, routes and driving times were chosen in order to reflect representative driving in these countries.**

Overview of the WLTP in-use driving behaviour database

Region	Mileage in km	Duration in h	No of short trips
Europe	432,572	8,003	200,813
India	73,694	1,824	17,358
Japan	49,868	1,255	55,944
Korea	32,399	790	26,972
USA	155,160	2,557	65,551
Total	**743,694**	**14,430**	**366,638**

Table 1

Database information

- The European data was collected in Belgium, France, Germany, Italy, Poland, Slovenia, Spain, Sweden and UK.

- The US customer data was collected in Atlanta, Denver, Los Angelos, San Diego and San Francisco.

- Number of vehicles/vehicle models:

- Europe: 126 M1 vehicles, 20 N1 vehicles,

- USA: 5 SUV

- Japan: 11 M1 vehicles, 13 N1 vehicles,

- Korea: 4 M1 vehicles, 4 N1 vehicles,

- India: 20 M1 vehicles, 11 N1 vehicles.

Measured/monitored data

- **The data consists of vehicle speed, engine speed (not for all vehicles), date and time of the day and trip number with a sample rate of 1 Hz.**

- **The acceleration was calculated using the following two approaches:**

  - ➢ • $a_i = (v_{i+1} - v_i)/3.6,$

  - ➢ • $a_i = (v_{i+1} - v_{i-1})/2/3.6,$

- **The second approach was used for the further analysis within the WLTP development work.**

Analysis approach

The following indicators were assigned to the datasets:

- trip number,

- short trip number within a trip (a short trip consists of consecutive datasets with v >= 1 km/h)

- acceleration (consecutive datasets with a > 0.1389 m/s² or 0.5 km/h/s),

- deceleration (consecutive datasets with a < -0.1389 m/s²),

- cruise (consecutive datasets with - 0.1389 m/s² <= a <= 0.1389 m/s²).

Structure of the report

Structure of the report

Structure of the report

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Structure of the report

Annex 1: Distance weighted joint average speed - maximum speed distributions of short trips

Annex 2: Time weighted joint vehicle speed - acceleration distributions

Annex 3: Distance weighted joint vehicle speed - acceleration distributions

Mileage statistics

- The total mileage of the data is almost 800 000 km.

- 4.7% of this mileage is related to trips below 3000 m. These trips were disregarded for the analysis of acceleration and deceleration distributions.

- Another 5.8% of the total mileage belongs to trips with faulty sections (jumps in vehicle speed etc.). This data was also excluded from the analysis.

- The remaining total mileage is 714 198 km. The distribution to the different countries, measurement campaigns and vehicles are shown in tables 8 to 26 in the report.

Mileage statistics

- **The number of monitoring days and the key parameters of the daily travelled distances are summarised in Table 27 to Table 31 of the report.**

- **More detailed information can be found in table "TB_daily_distance" in the Access database.**

- **There are big differences between the countries as well as between different measurement campaigns.**

- **The lowest average daily distance was found for Poland (30 km), the highest for the UK (188 km, N1 vehicle).**

Driving statistics

- The key parameters (duration, distance driven, stop duration, average and maximum speeds) for all vehicles are shown in tables 32 to 38 of the report.

- There are significant differences between the individual vehicles (drivers) within a country, but there are also significant differences between the countries, even within Europe.

- The measurement campaigns in Poland and Spain are dominated by urban traffic conditions, while the campaign in Italy has a high influence of rural and motorway traffic.

- This is also reflected in the country related vehicle speed distributions, shown in Figure 1 and Figure 2.

Vehicle speed distributions

Figure 1

Vehicle speed distributions

Figure 2
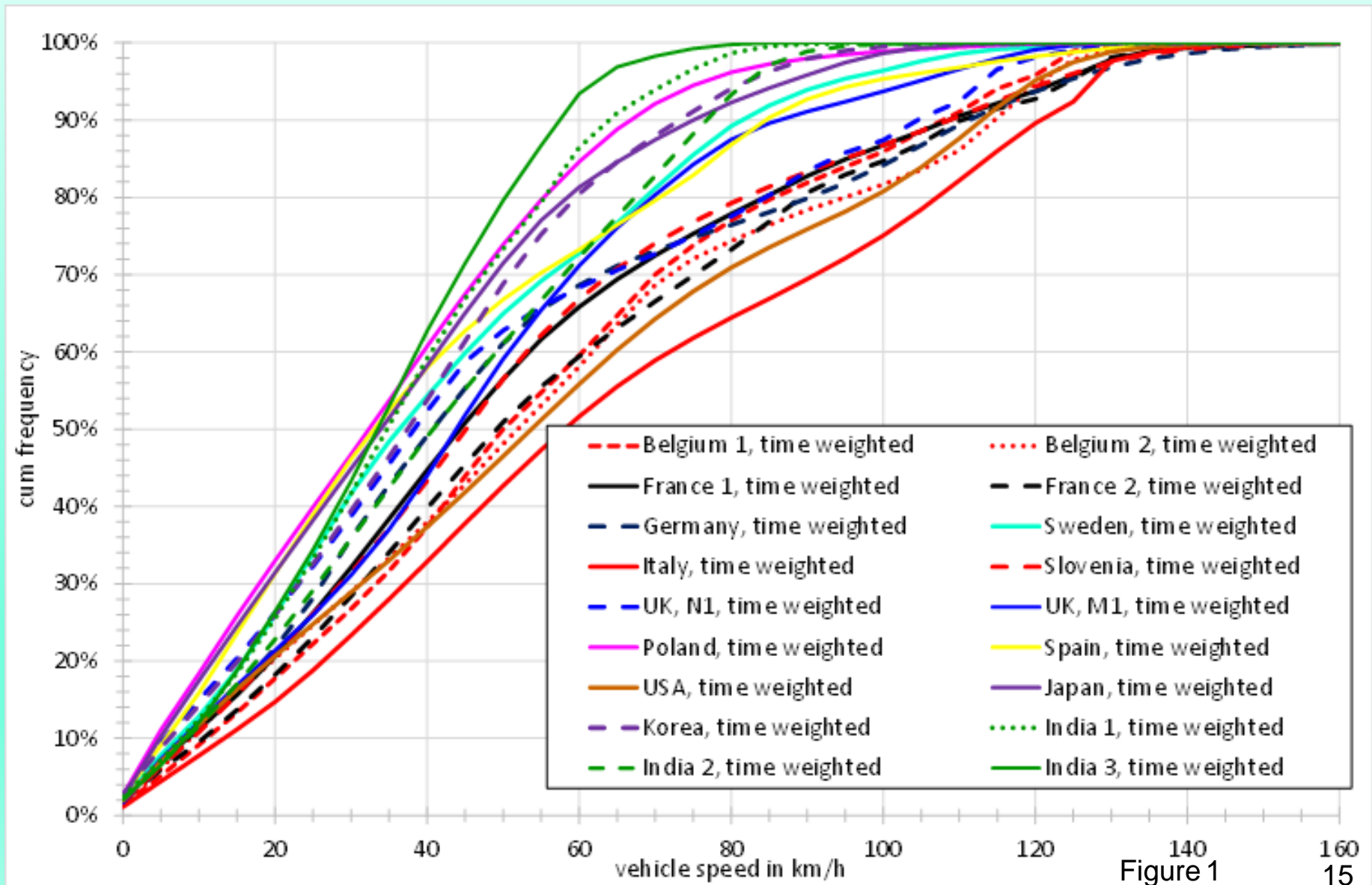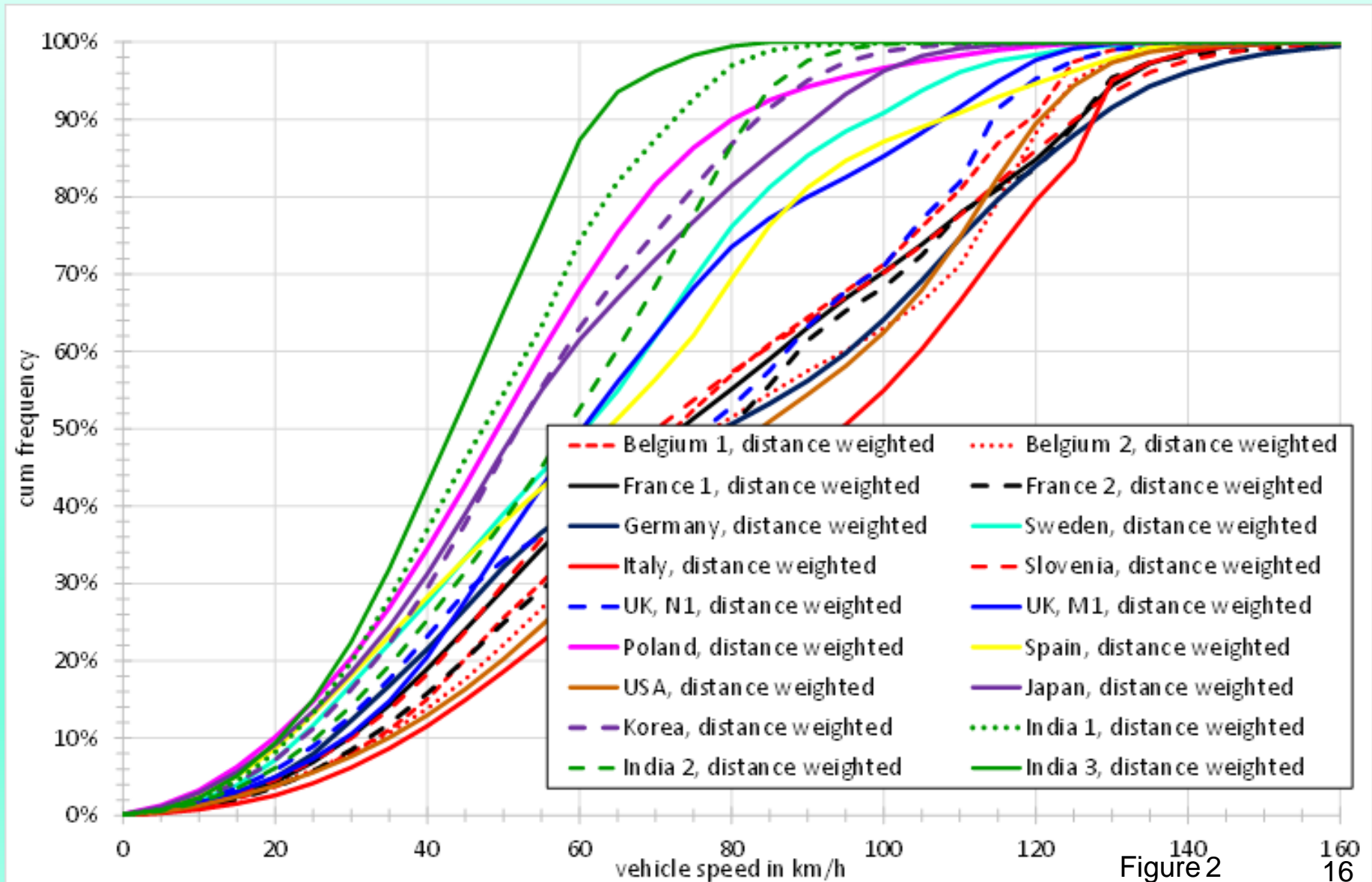
Vehicle speeds, urban, rural, mot

- **The customer datasets Belgium 1, France 1, France 2, Germany, Italy, Slovenia, UK M1, Poland and Spain came along with road category indicators for urban, rural and motorway.**

- **The key parameters of these datasets with respect to mileage, driving time and average speeds per vehicle are summarised in Table 39 to 47 of the report.**

- **Examples per dataset are shown in the following figures.**
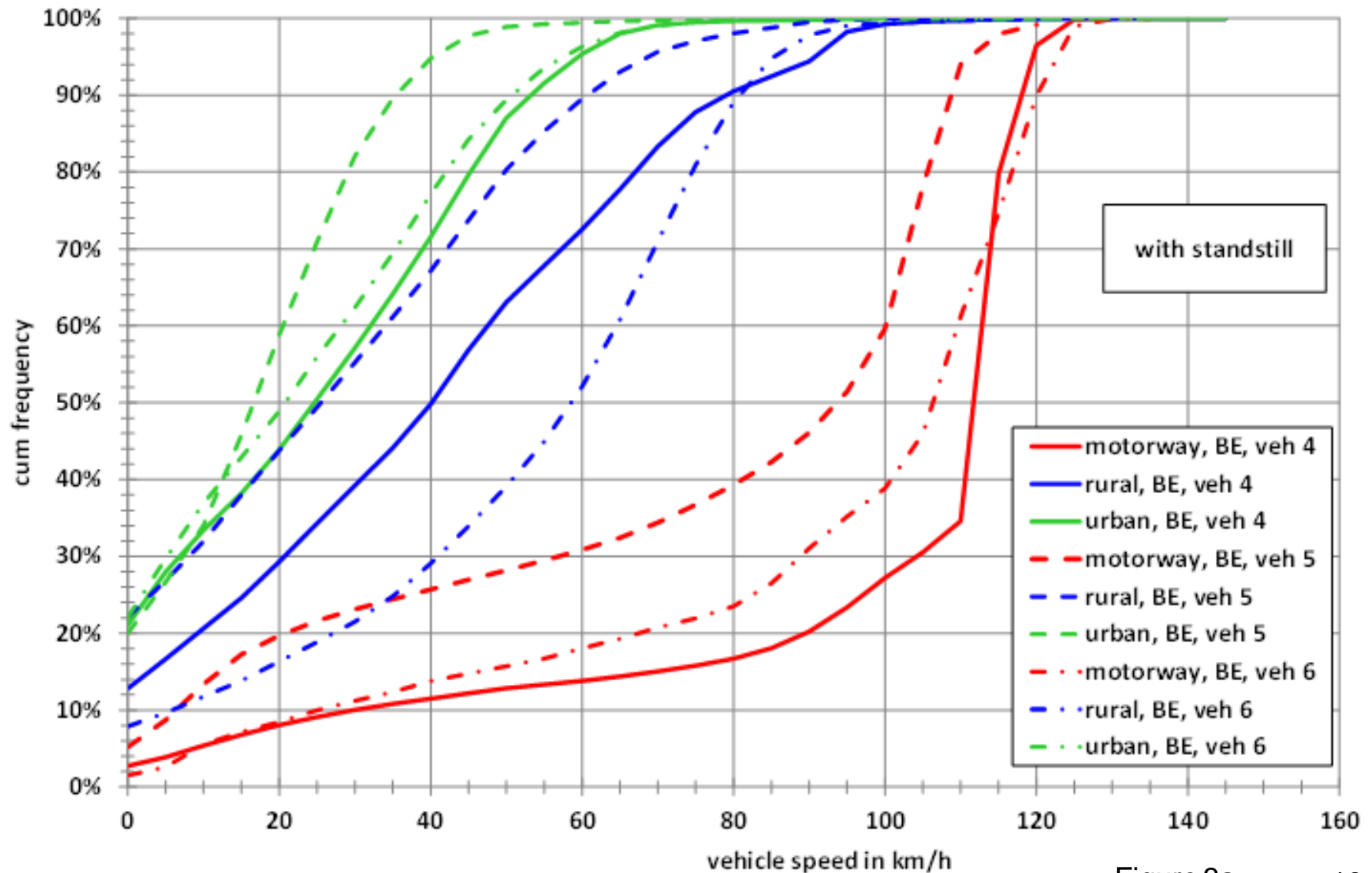
v distributions, urban, rural, mot
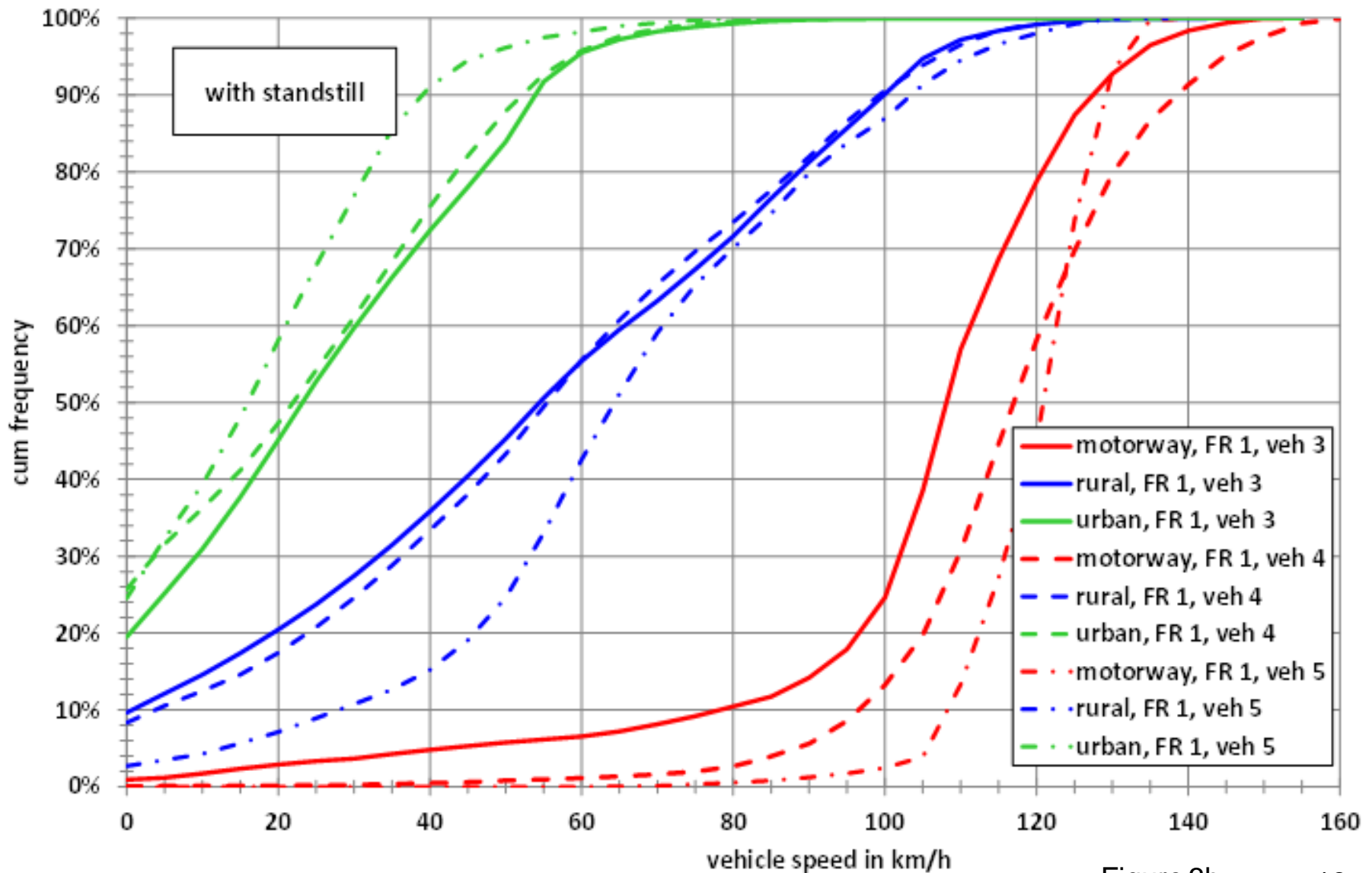

Figure 3a

v distributions, urban, rural, mot

Figure 3b

Figure 3c
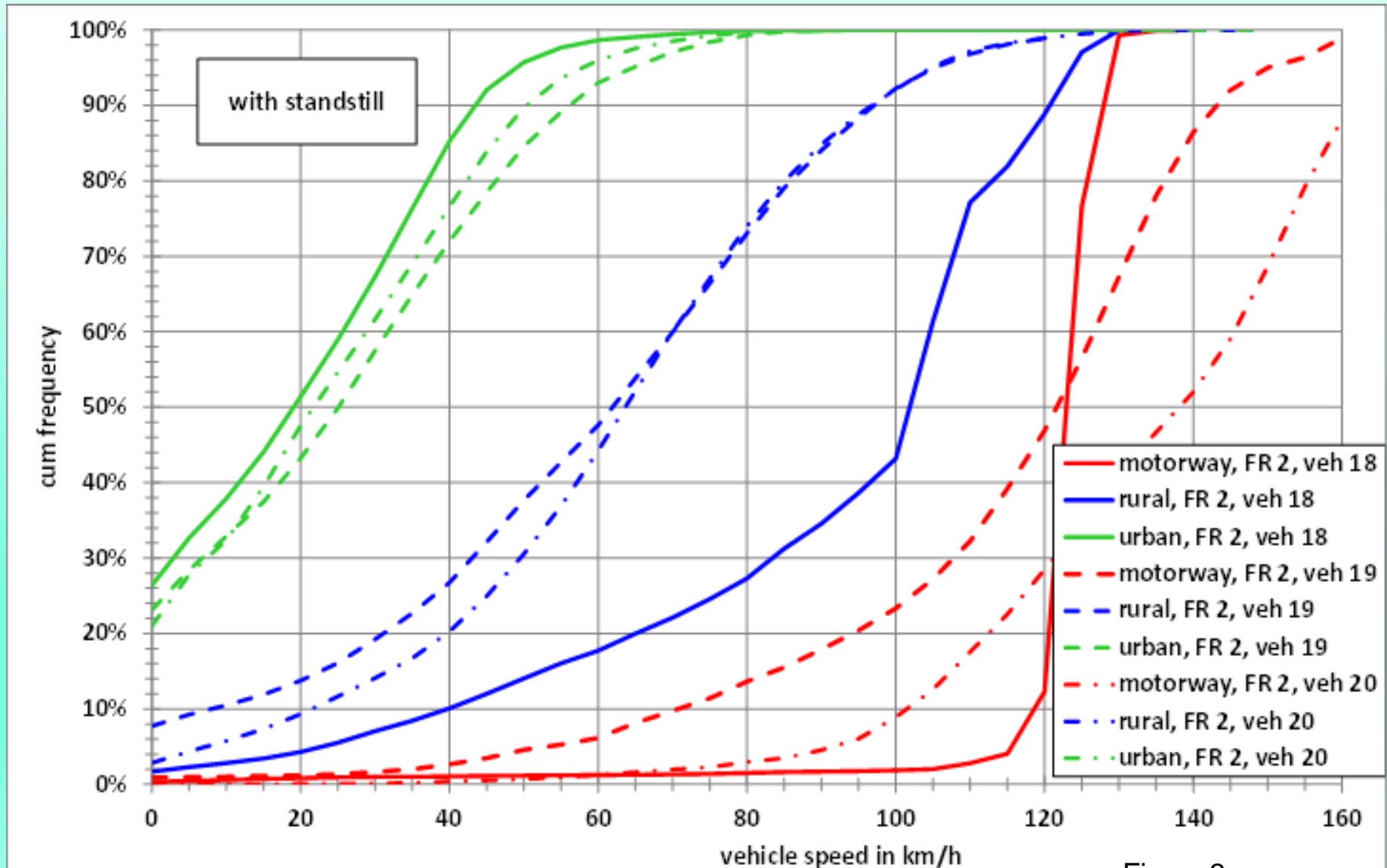
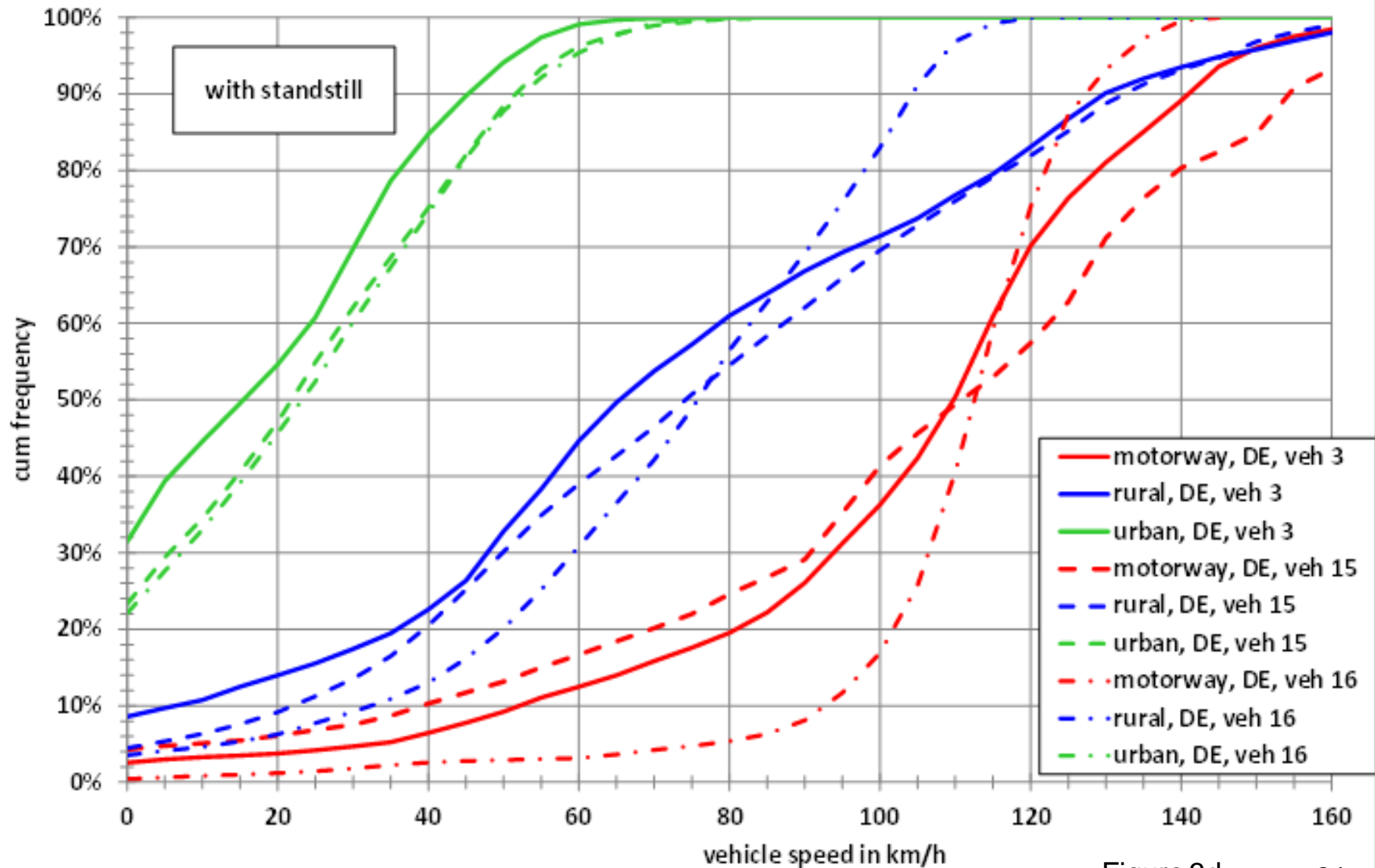# v distributions, urban, rural, mot

Figure 3d

Figure 3e

v distributions, urban, rural, mot

Figure 3f
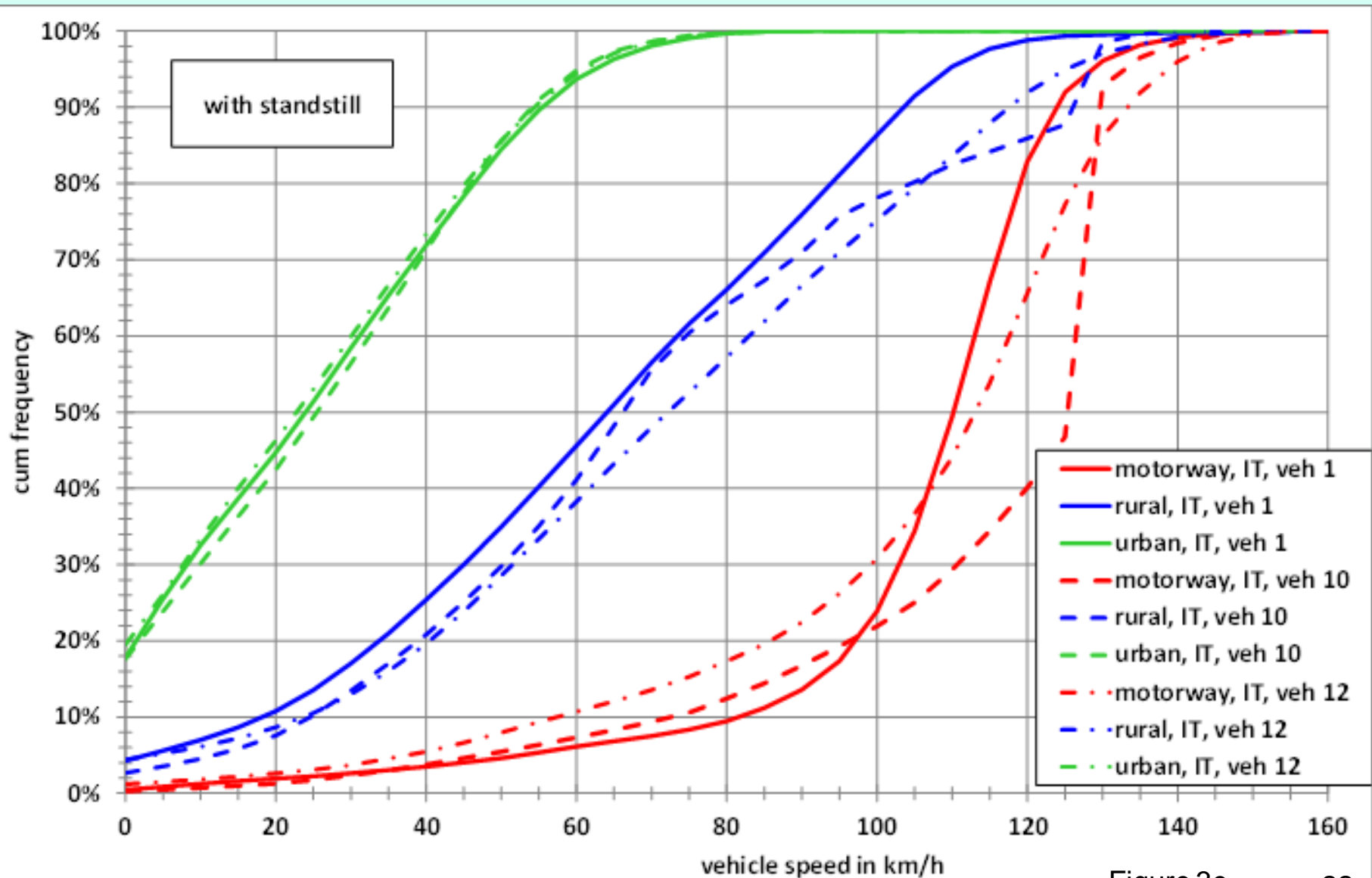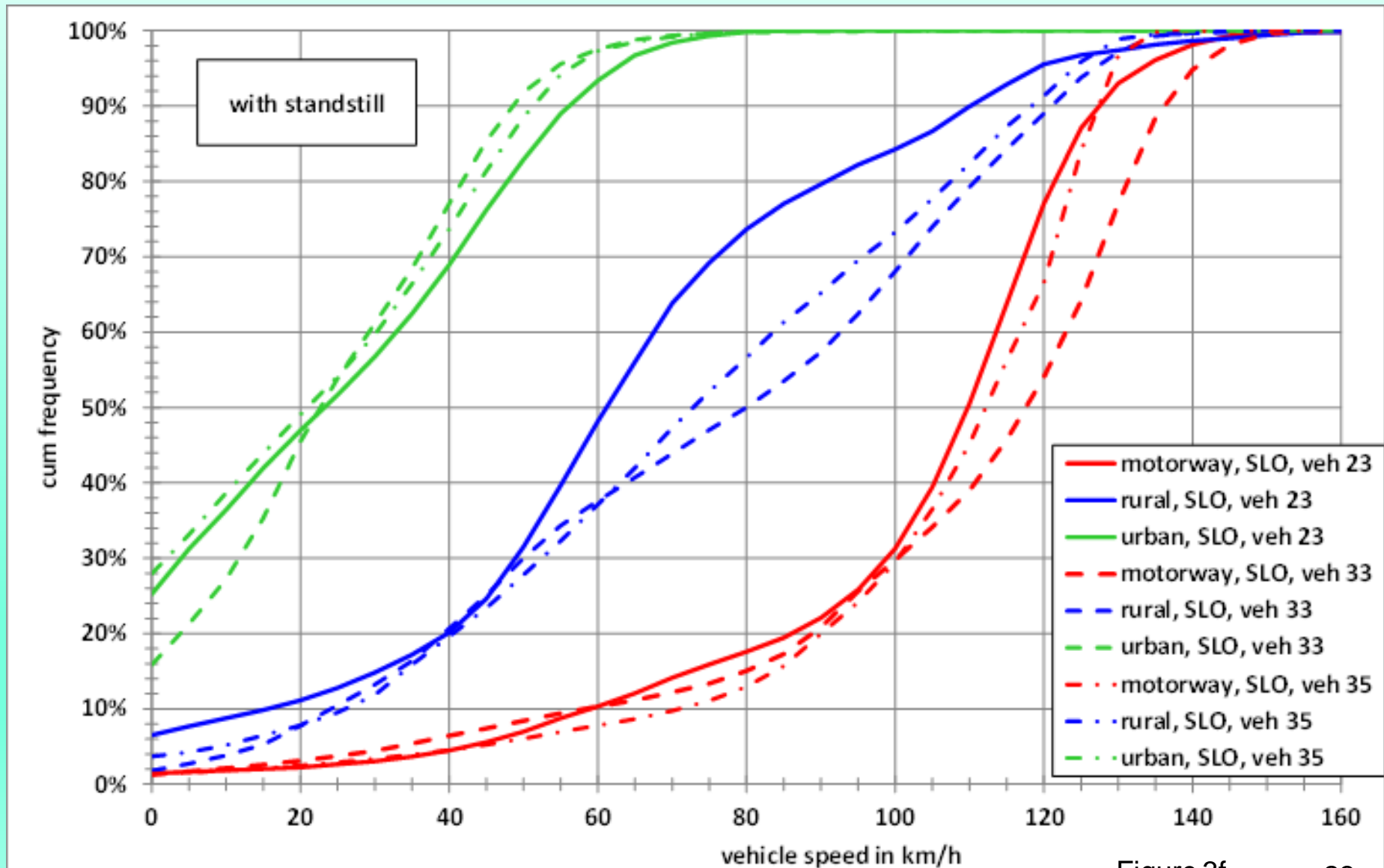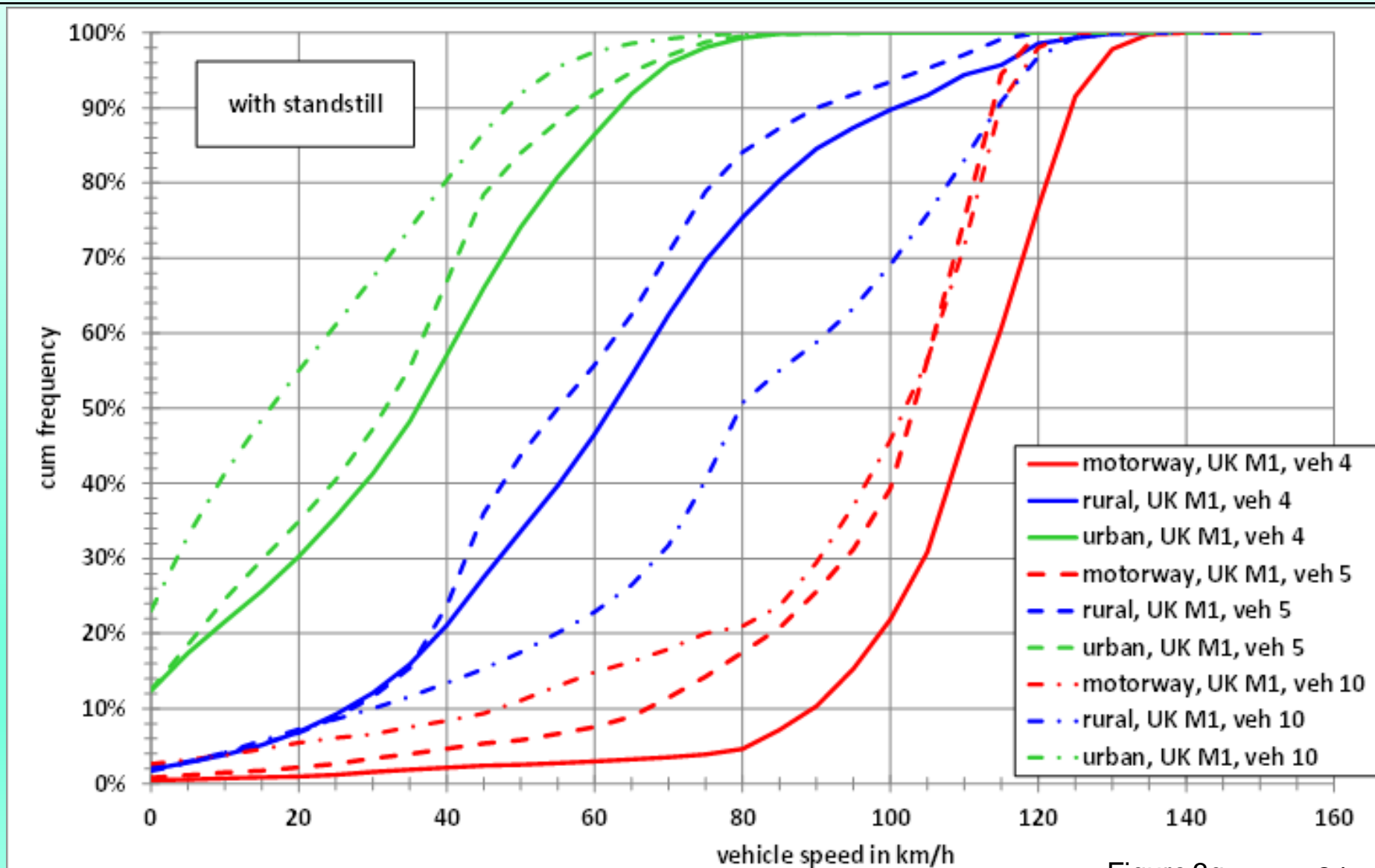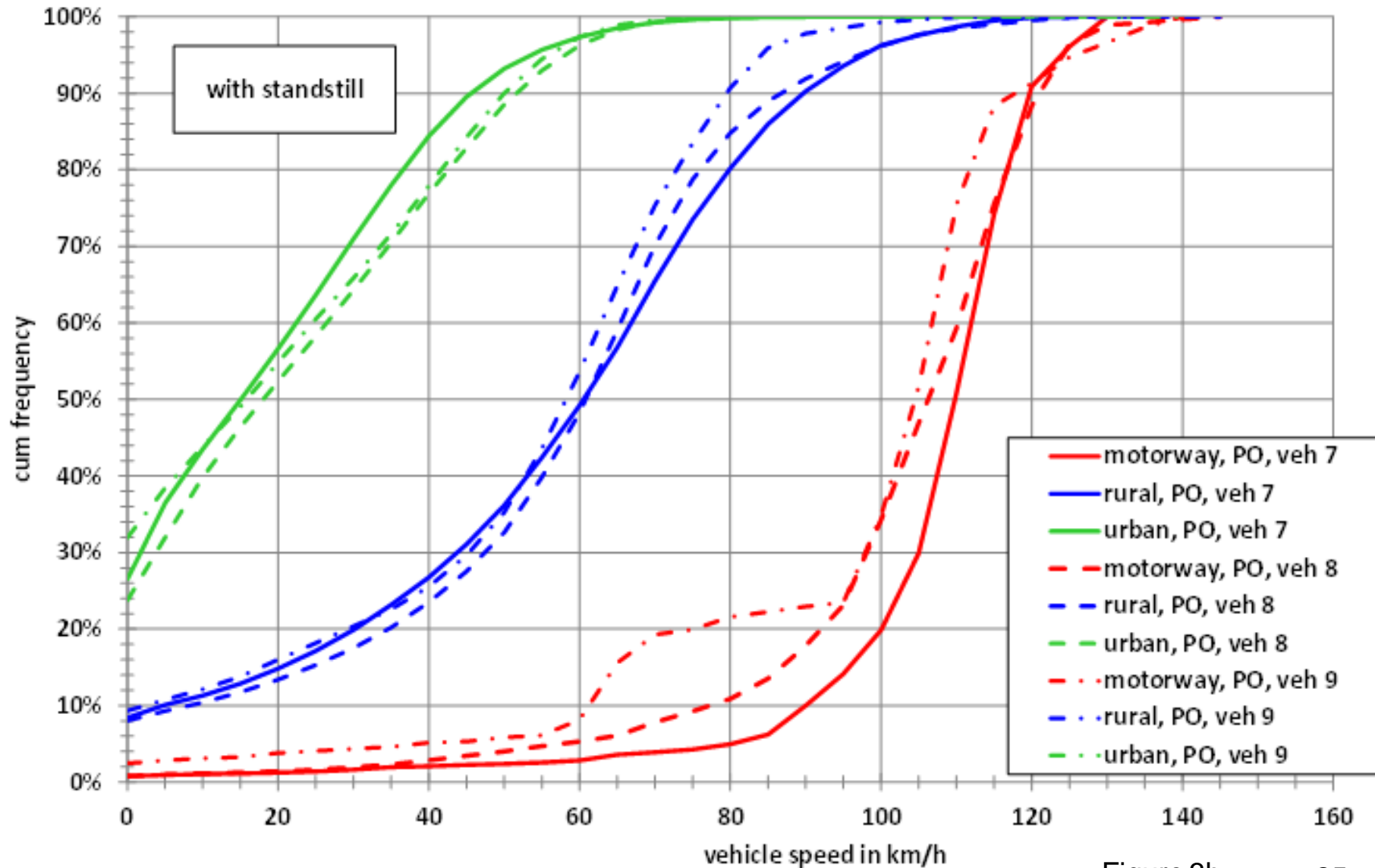
v distributions, urban, rural, mot

Figure 3g

Figure 3h
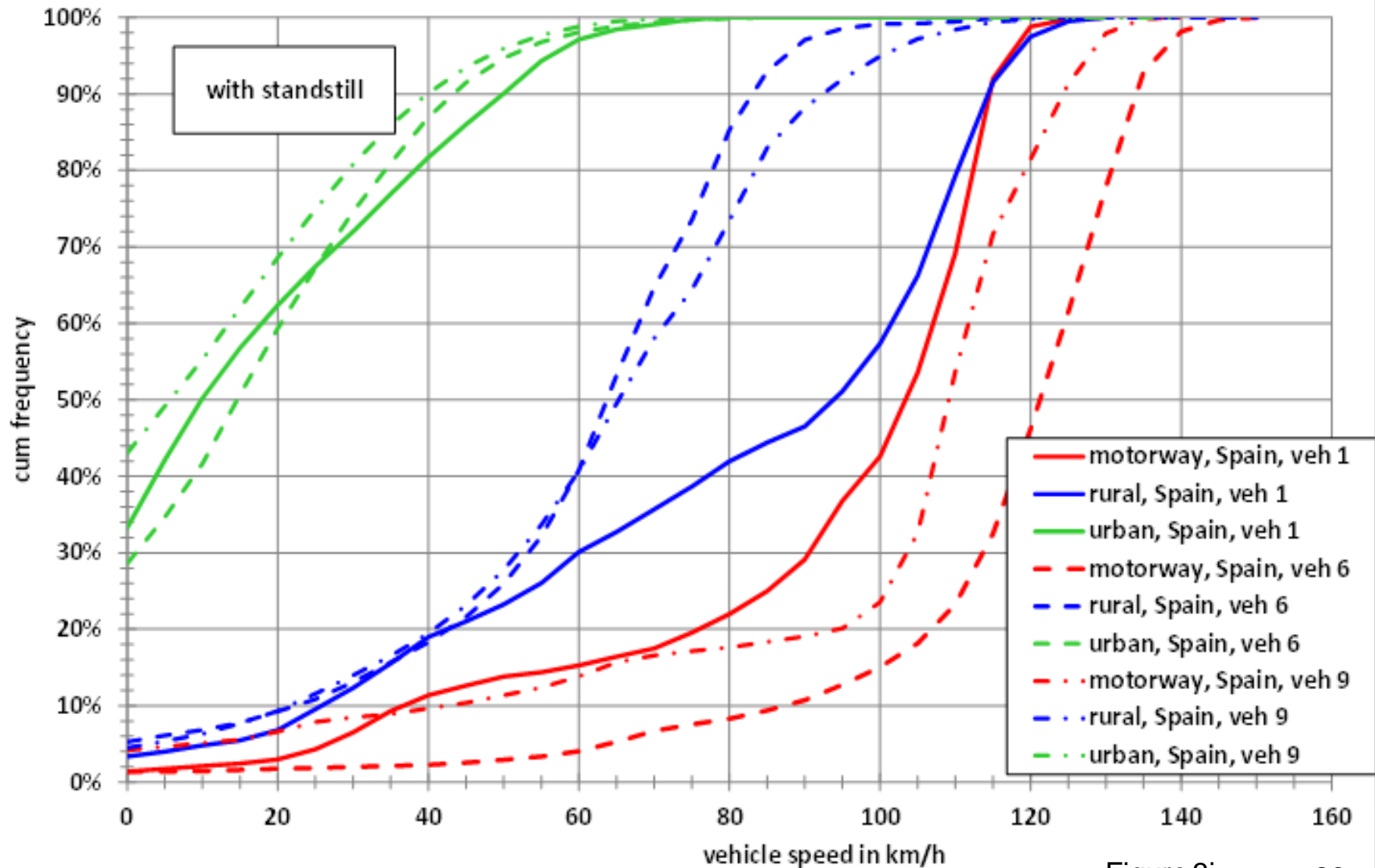
Figure 3i

- **For the further analysis the data was separated into stop periods and short trips. Stop periods are defined as connected time sequences with vehicle speeds below 1 km/h, short trips are connected time sequences with vehicle speeds >= 1 km/h.**

- **Figure 4 to Figure 7 show the stop phase duration distributions for different regions and different countries within Europe, number weighted and duration weighted.**

- **Number weighted means that the percentages on the y-axis indicate the percentage of the whole number of stop phases with a duration of the corresponding x-axis value.**

Stop phases

- **Duration weighted means that the percentages on the y-axis indicate the percentage of the whole stop duration with a duration of the corresponding x-axis value.**

- **Figure 8 shows the number weighted stop duration distributions for Europe, separated into three road categories.**
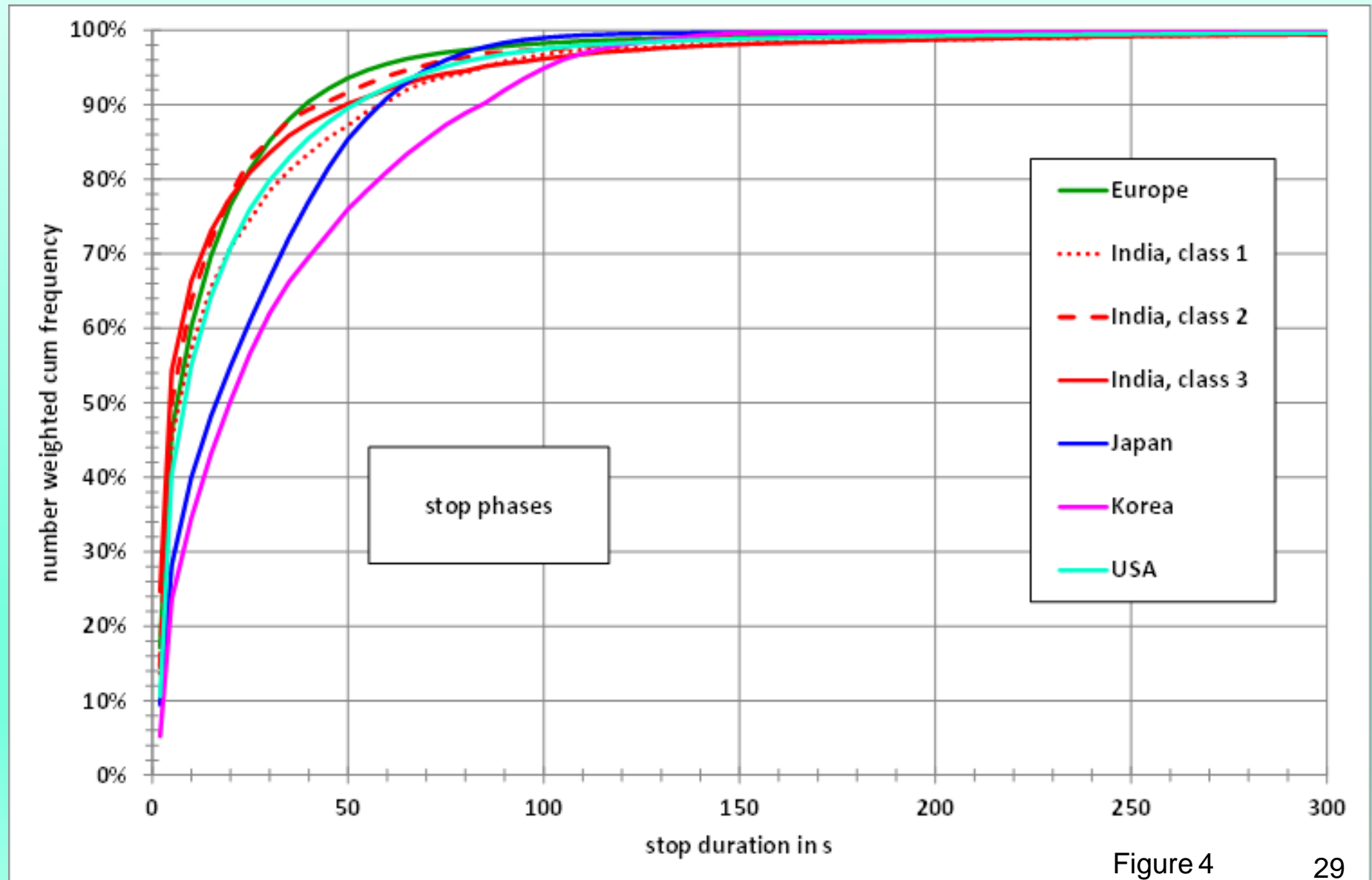
Stop duration distribution

Figure 4
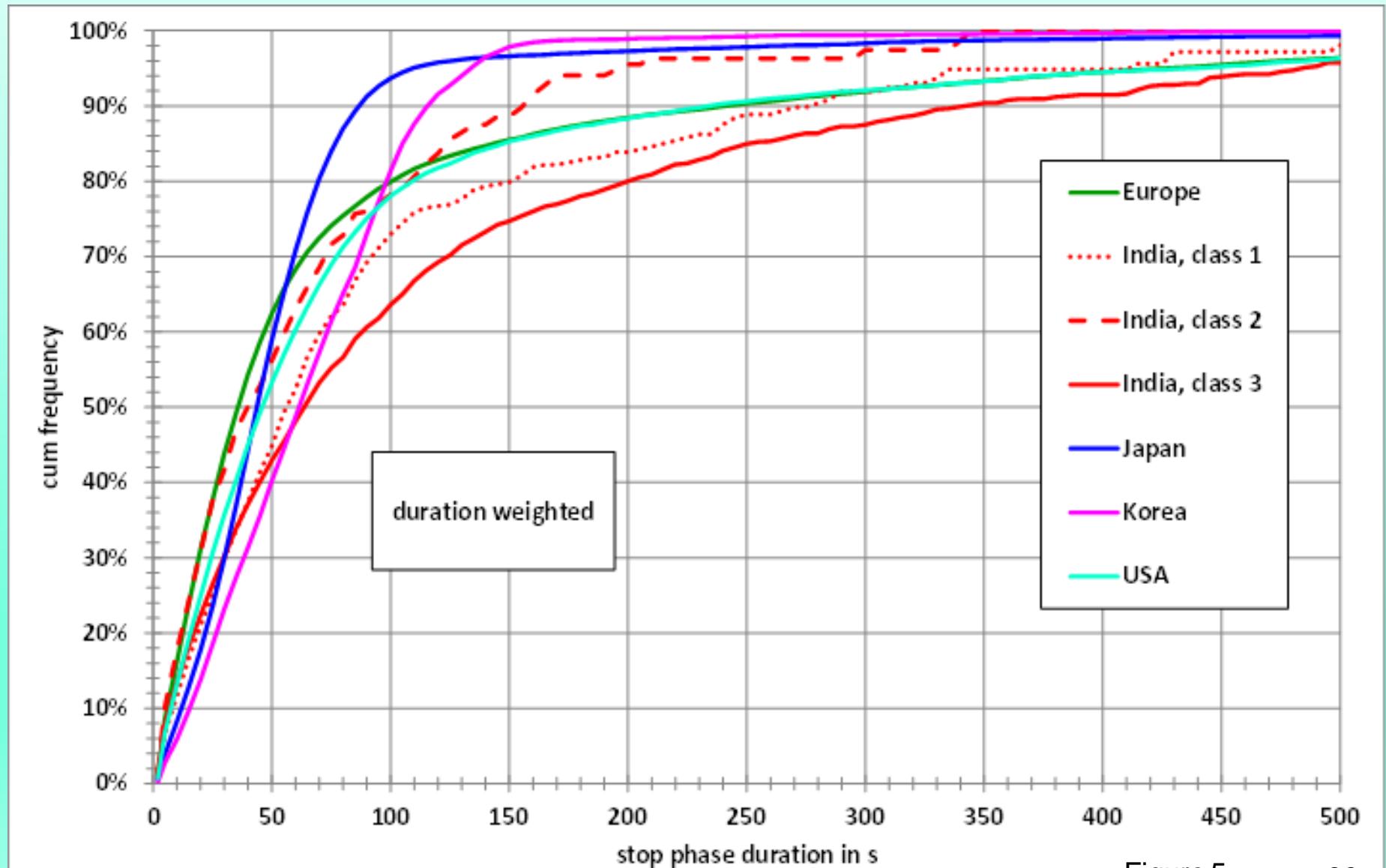
Stop duration distribution
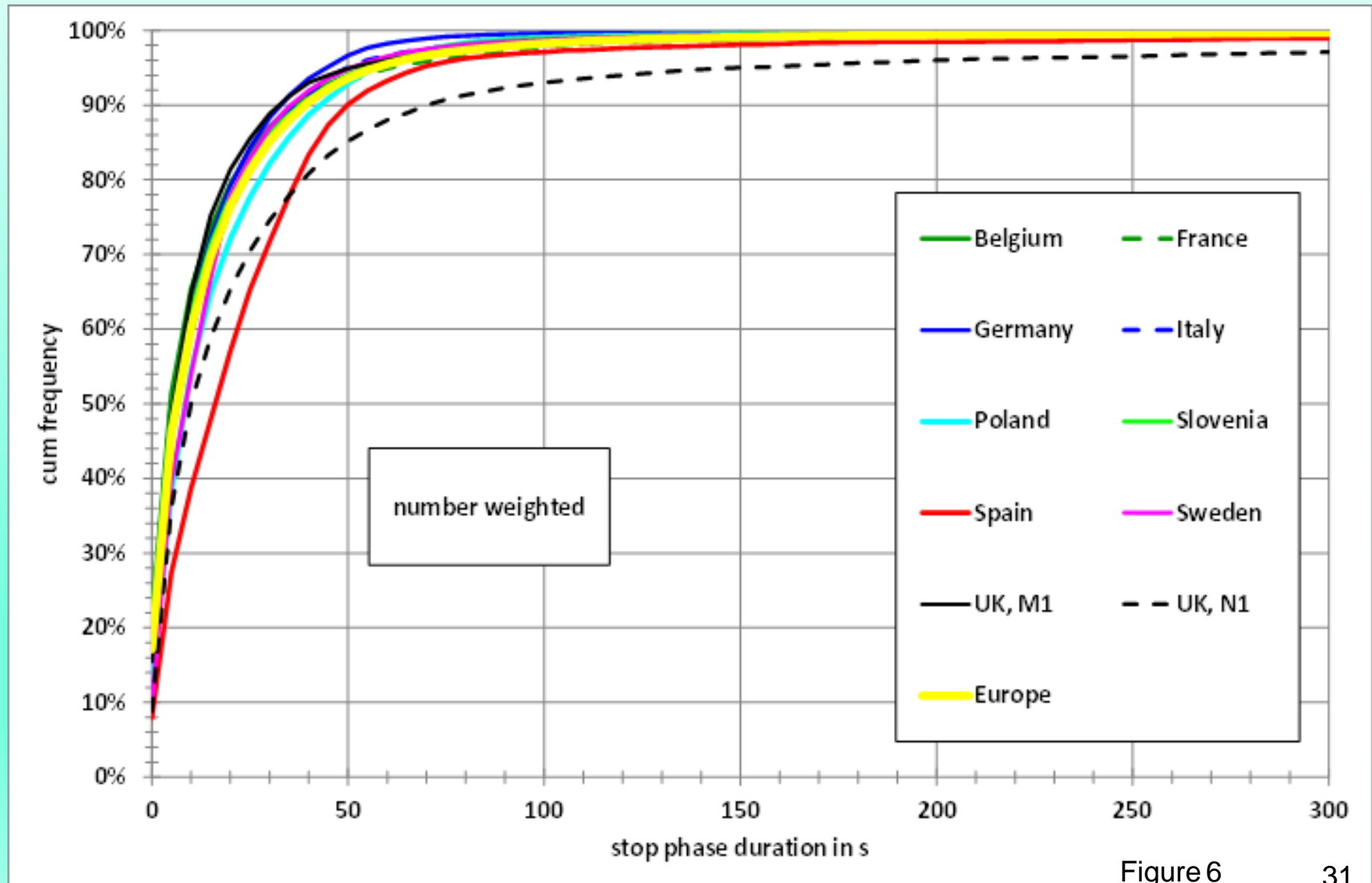

Figure 5

Stop duration distribution

number weighted
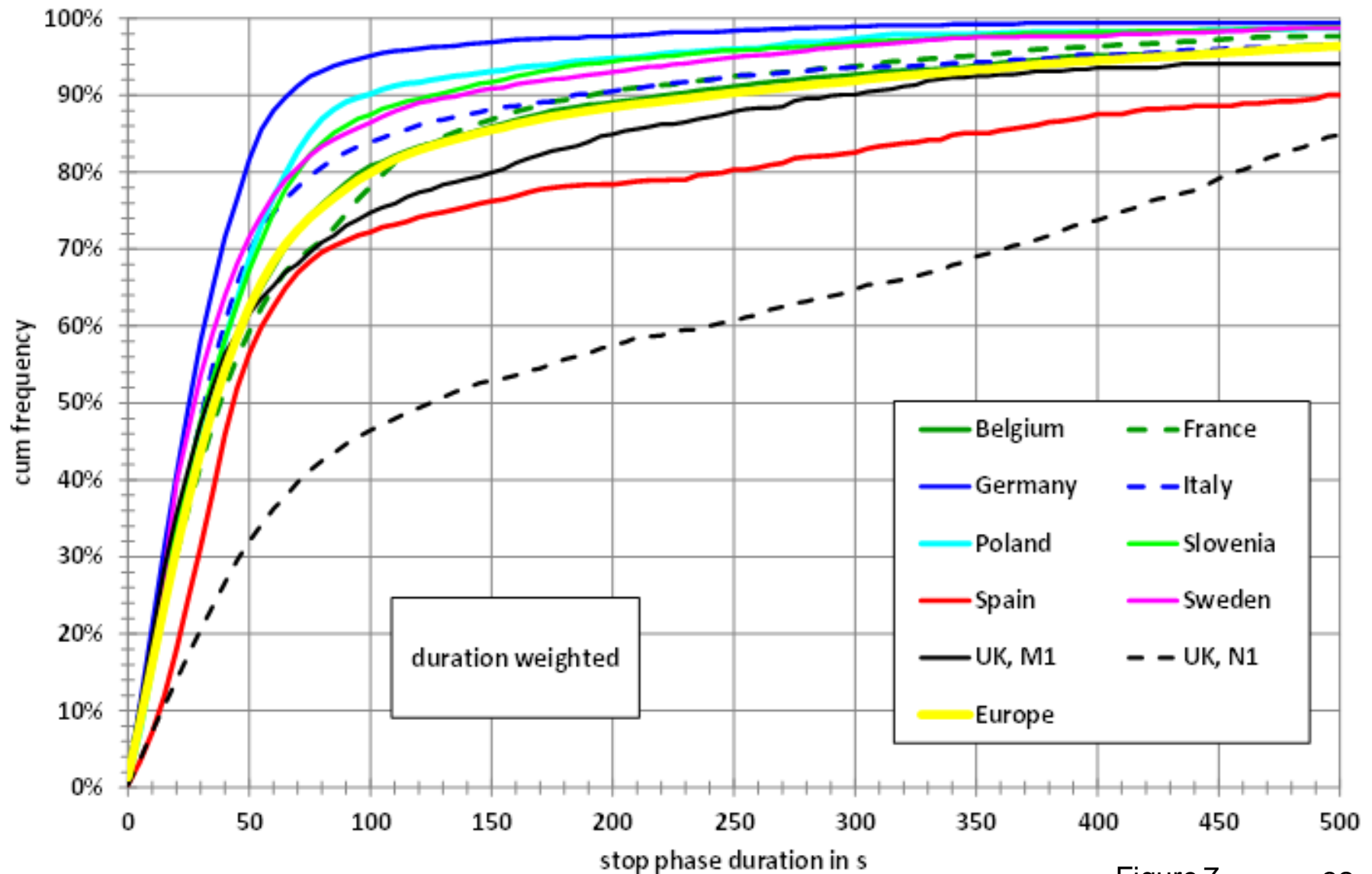
Figure 6

Stop duration distribution

Figure 7

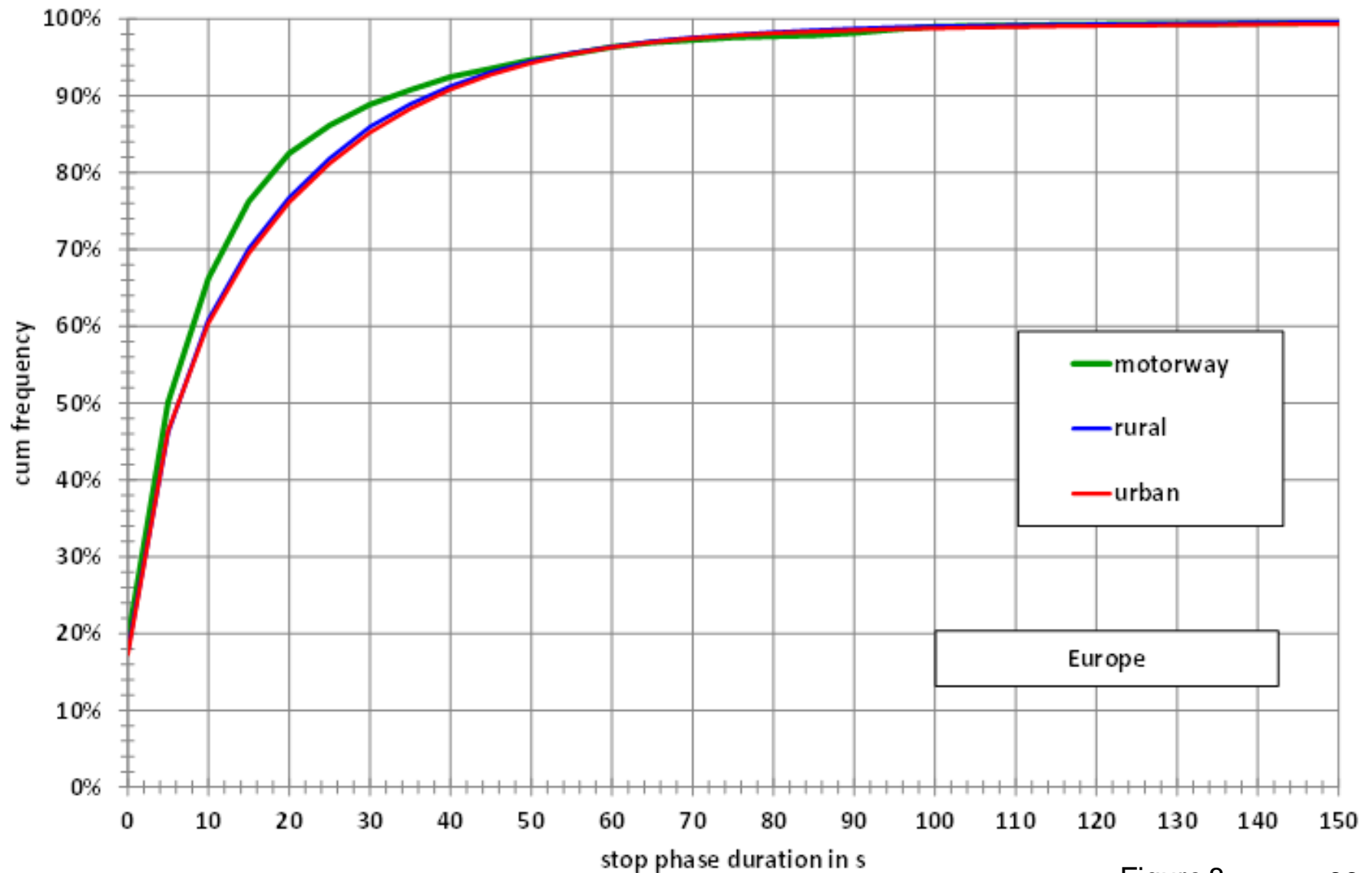# Stop duration distribution

Figure 8

Short trips

- **Figure 9 to Figure 12 show the short trip distance distributions for different regions and different countries within Europe, number weighted and distance weighted.**

- **Figure 13 and Figure 14 show number and distance weighted short trip distance distributions for Europe, separated for different road categories.**

- **In order to assess the occurrence of creeping situations the short trips were binned with respect to v_{max} and the distances were summed up per v_{max} bin and related to the total distance per road category.**

- **The results are shown for different road categories for some European countries in Table 53 to 60 of the report.**

- **Distance weighted joint frequency distributions of average speed / maximum speed for short trips are shown in annex 1.**
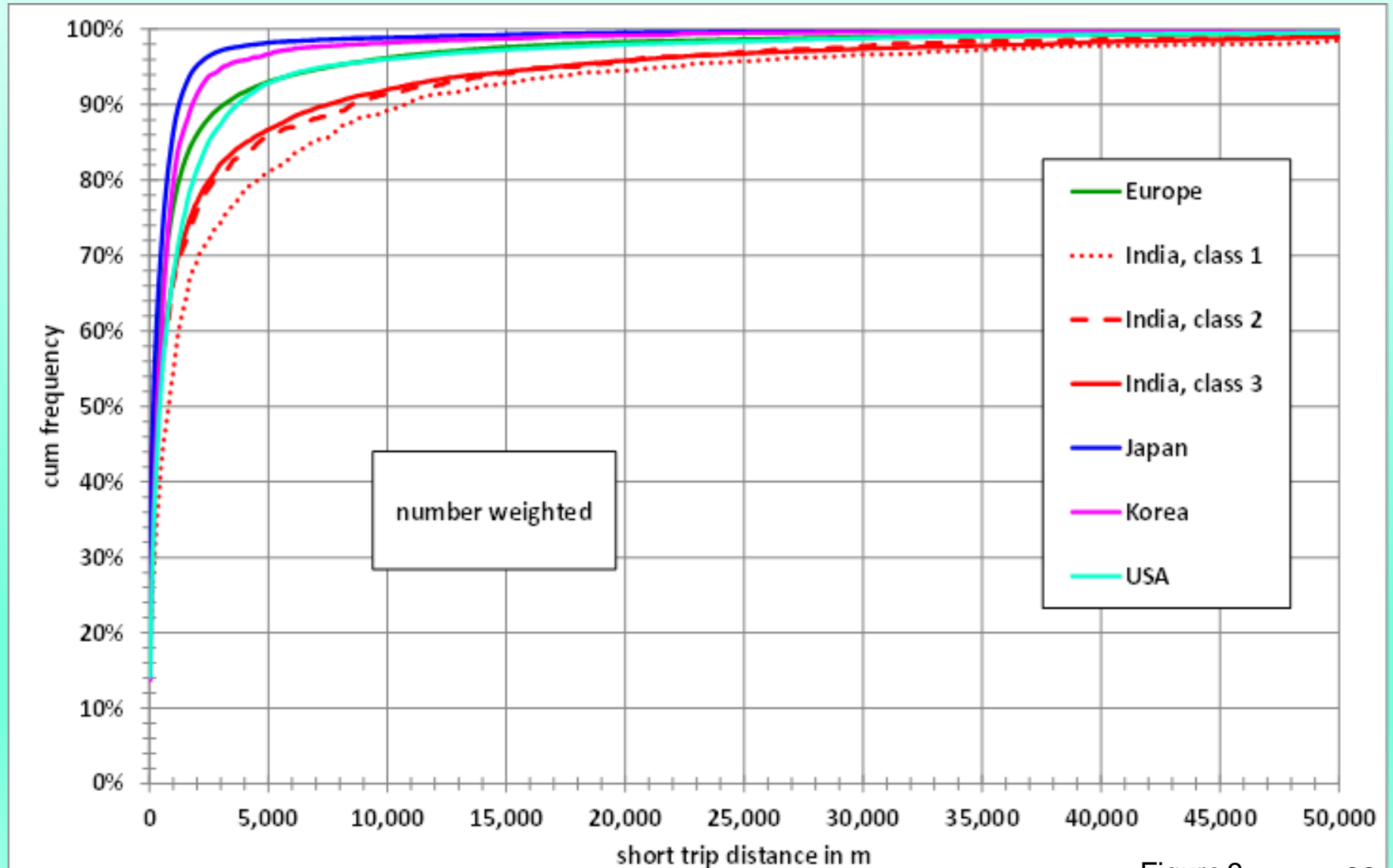
Short trip distribution
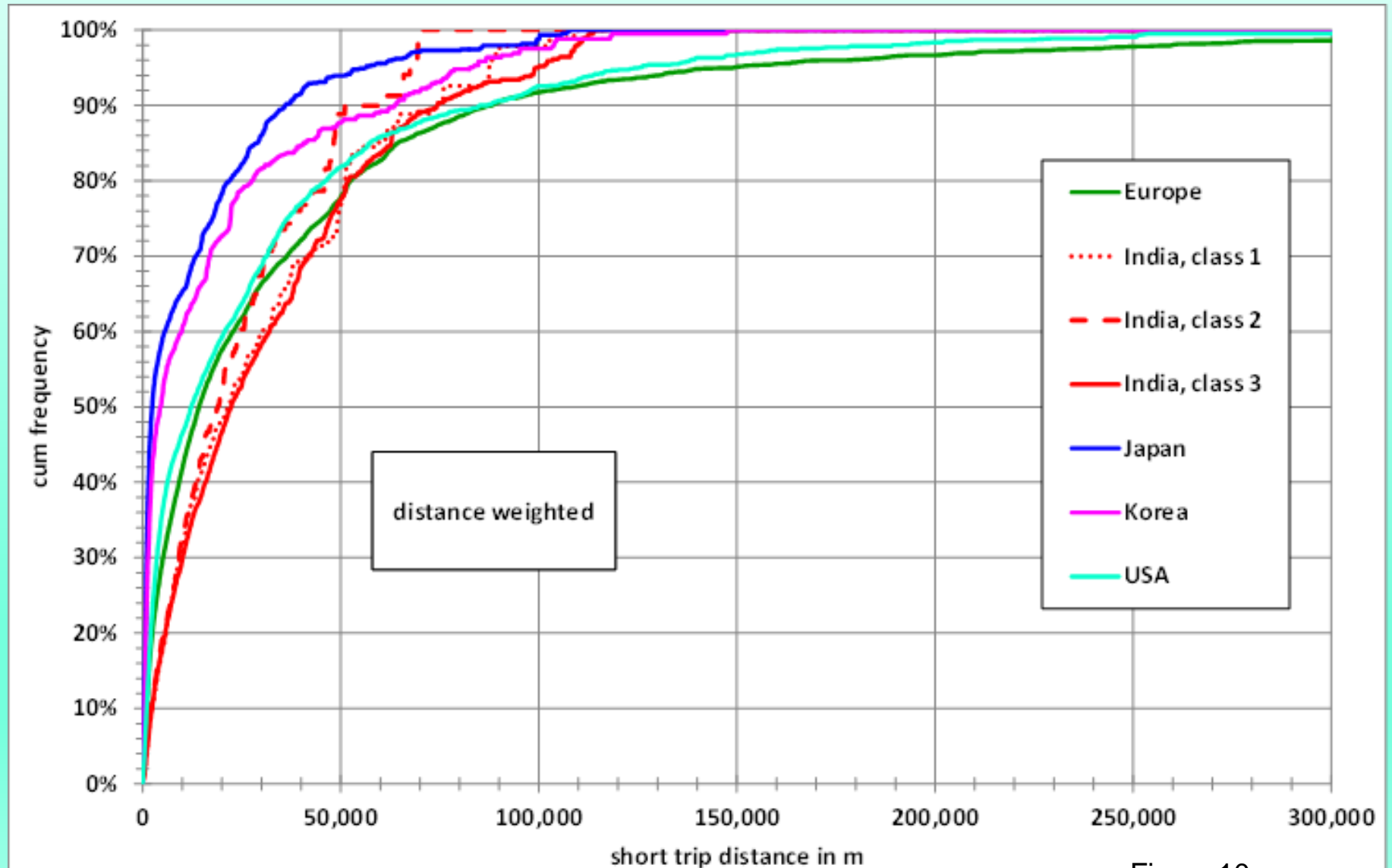

Figure 9

Short trip distribution
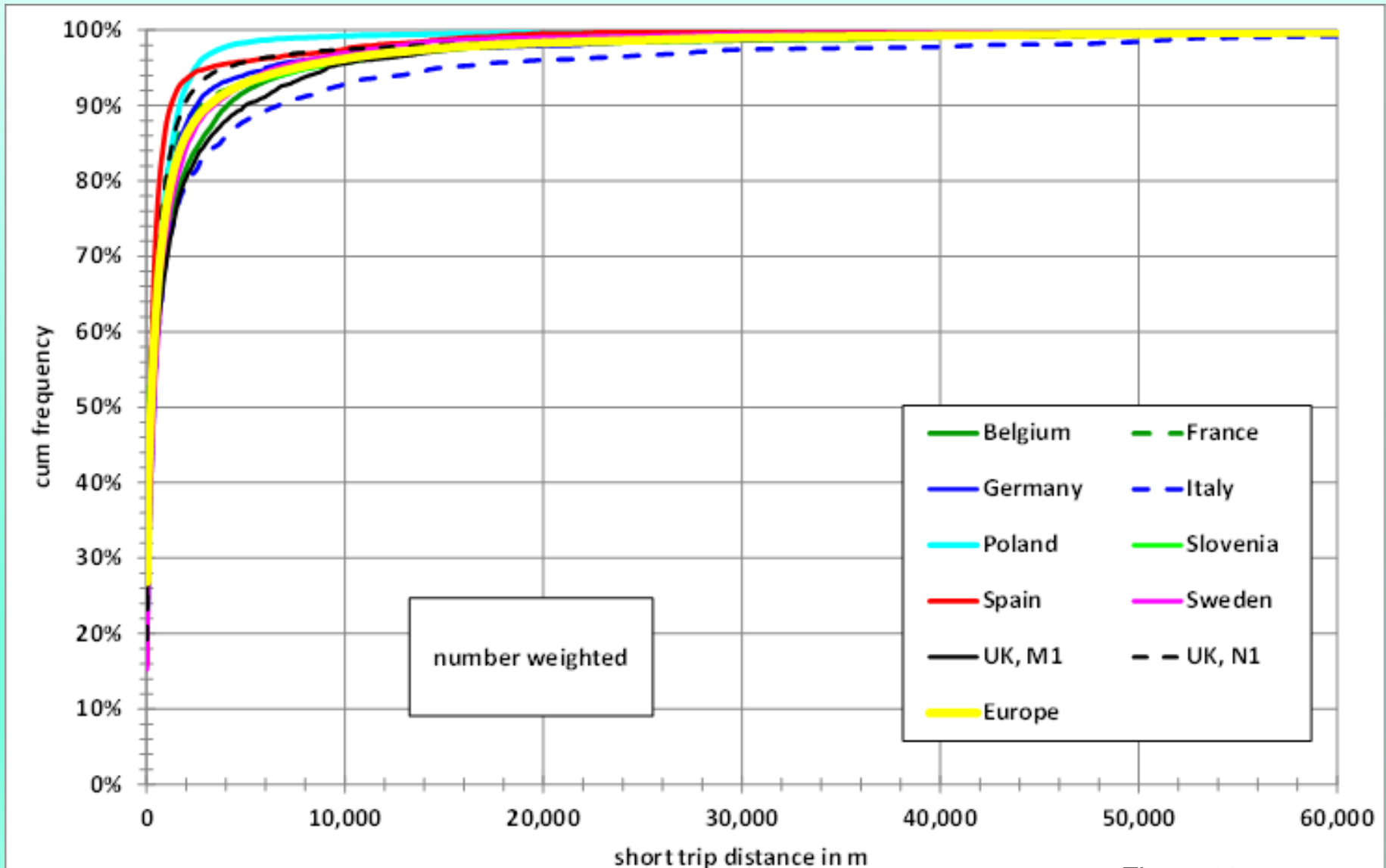

Figure 10

Short trip distribution

Figure 11
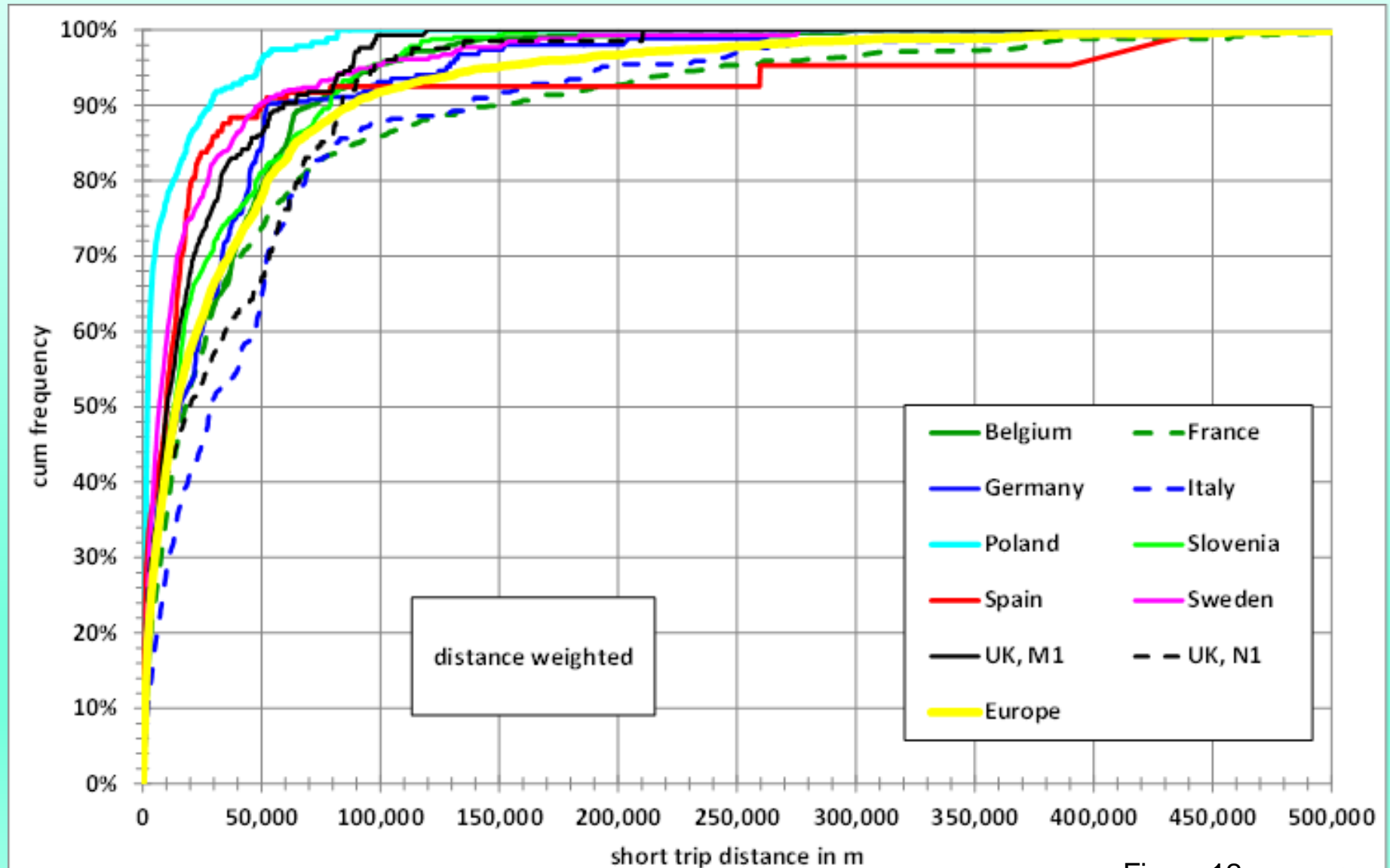
Short trip distribution

Figure 12

Short trip distribution
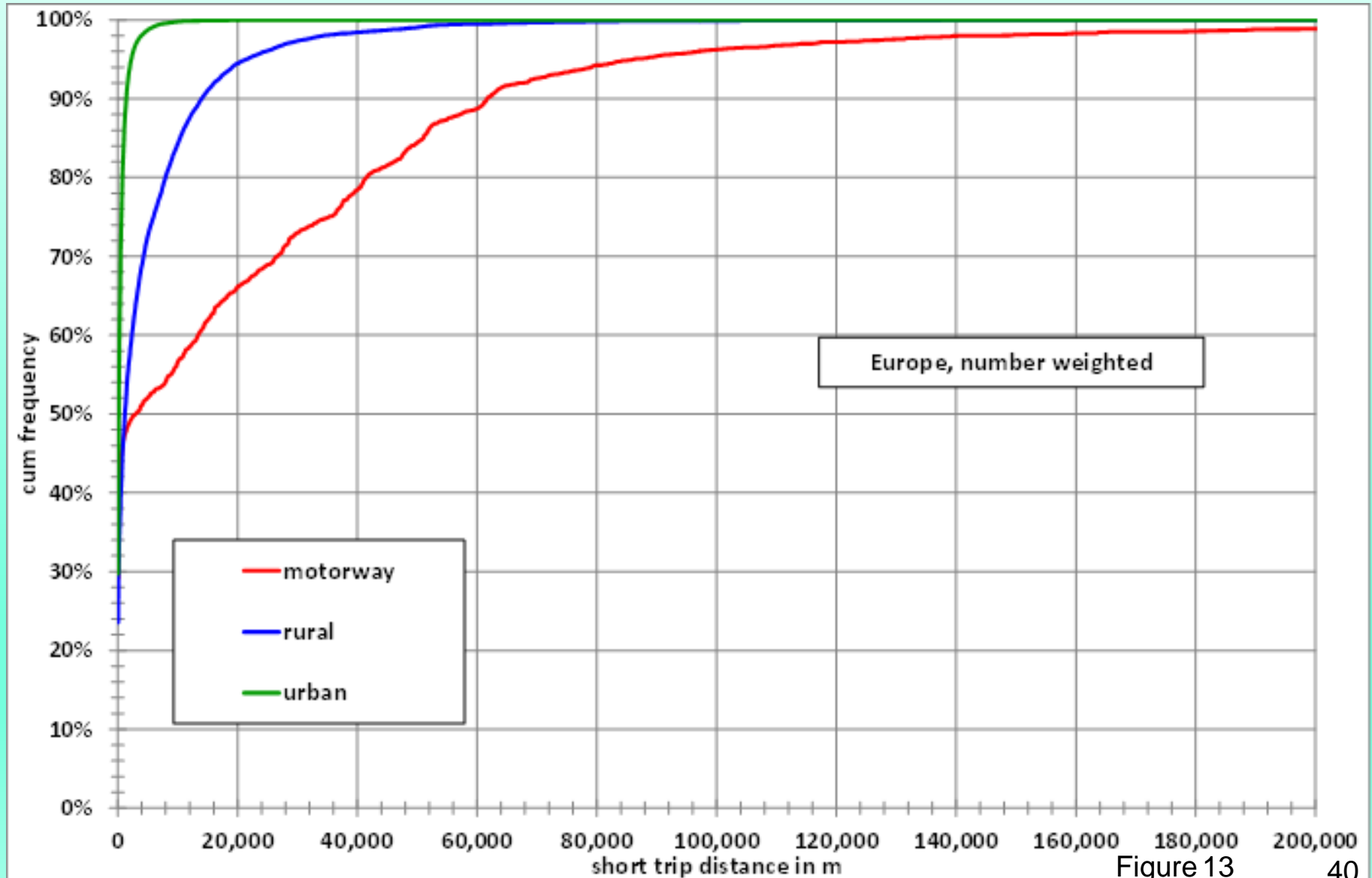

Figure 13

40

Short trip distribution

Figure 14

Acceleration duration distributions

- **Acceleration phases are specified as consecutive time samples with a > 0.5 km/h/s or 0.1389 m/s². The following key parameters of such phases were collected in a separate table (TB_acc) per vehicle and trip:**

  - ➢ **Date, Time, Duration, Distance,**

  - ➢ **v_min, v_ave, v_max, stddev_v,**

  - ➢ **a_min, a_ave, a_max,**

  - ➢ **v*a_min, v*a_ave, v*a_max.**

- **In order to ease the calculation of duration and distance related distributions the results were binned for both values (2 s for the duration and 5 m for the distance). The analysis was performed for v_{max} <= 60 km/h, 60 km/h < v_{max} <= 80 km/h and v_{max} > 80 km/h separately.**

Acceleration duration distributions

- **The following figures show the duration distributions for individual vehicles in Europe and for the different regionsfor the lowest v_{max} class.**

- **The distributions for the two other v_{max} classes are shown in the report.**

- **The distance distributions are also included in the report and show similar trends within the three v_{max} classes.**

- **Figure 17 shows the average duration distributions for the EU and the three v_{max} classes.**

- **Figure 18 shows the corresponding results for the average distance distributions.**

Acceleration distributions

Figure 15

Acceleration distributions

v_max <= 60 km/h

Legend:
- average EU
- average Japan, M1
- average Japan, N1
- average Korea
- average India, class 1
- average India, class 2
- average India, class 3
- average US

cum frequency vs. acceleration phase duration in s
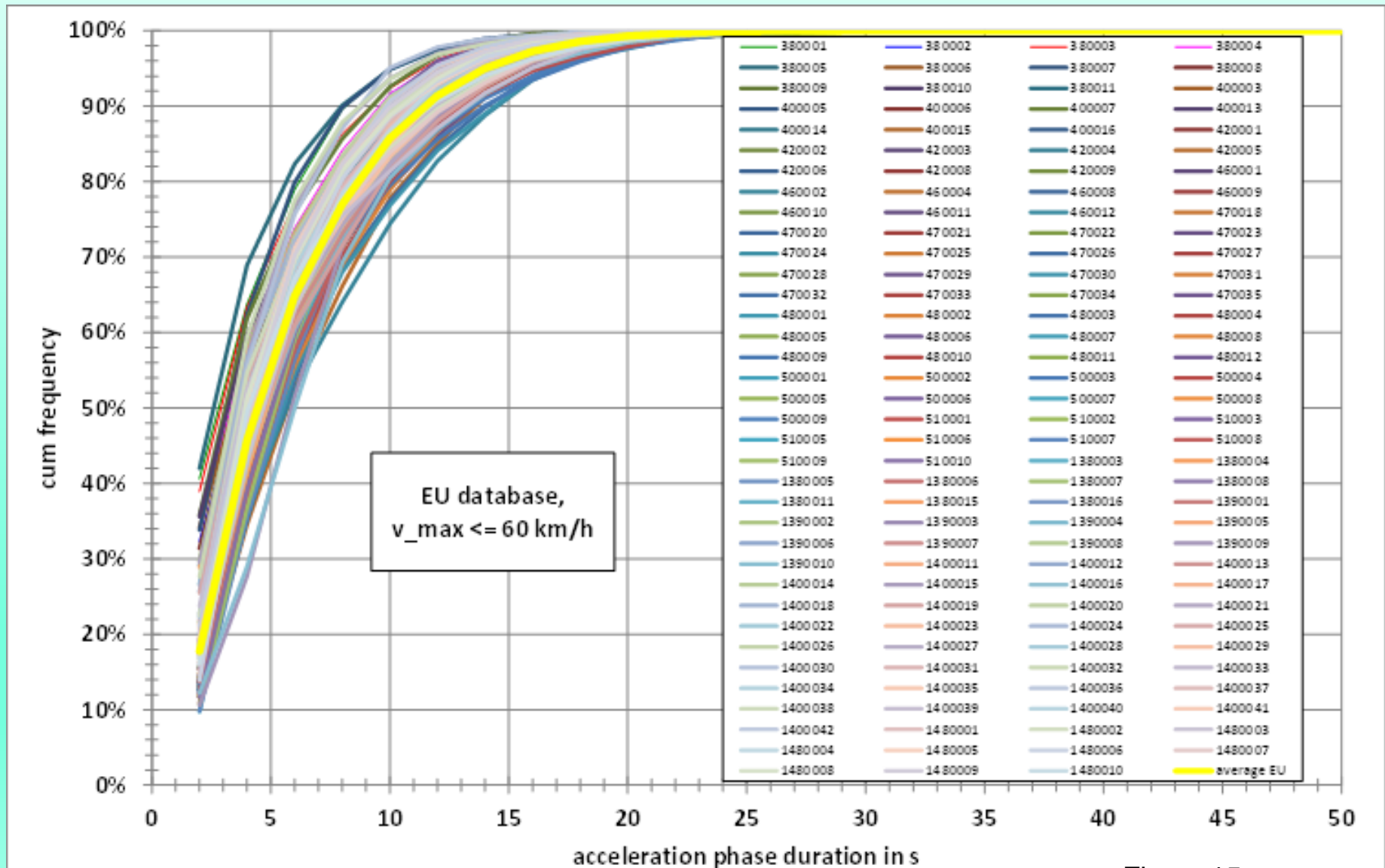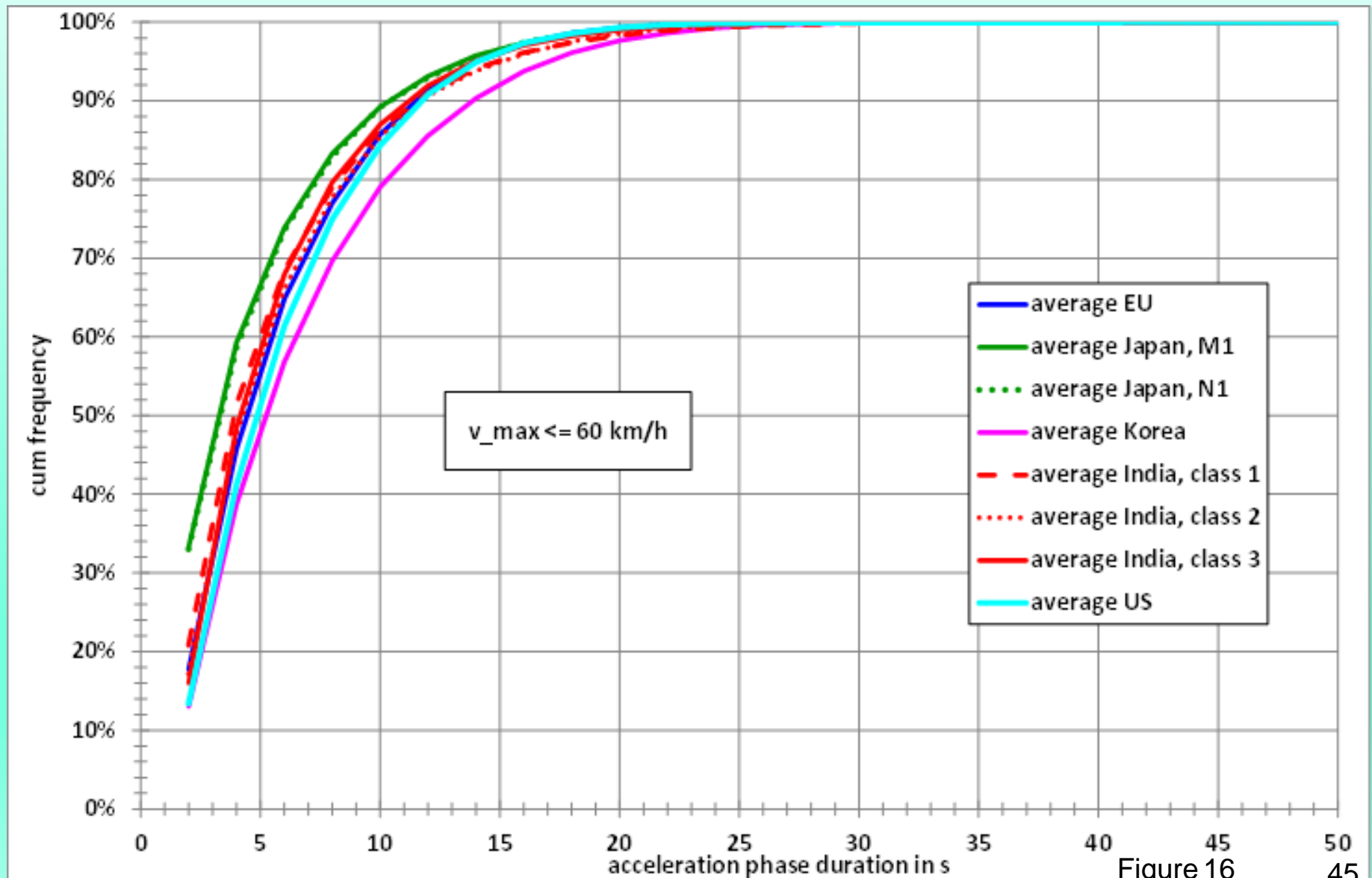
Figure 16
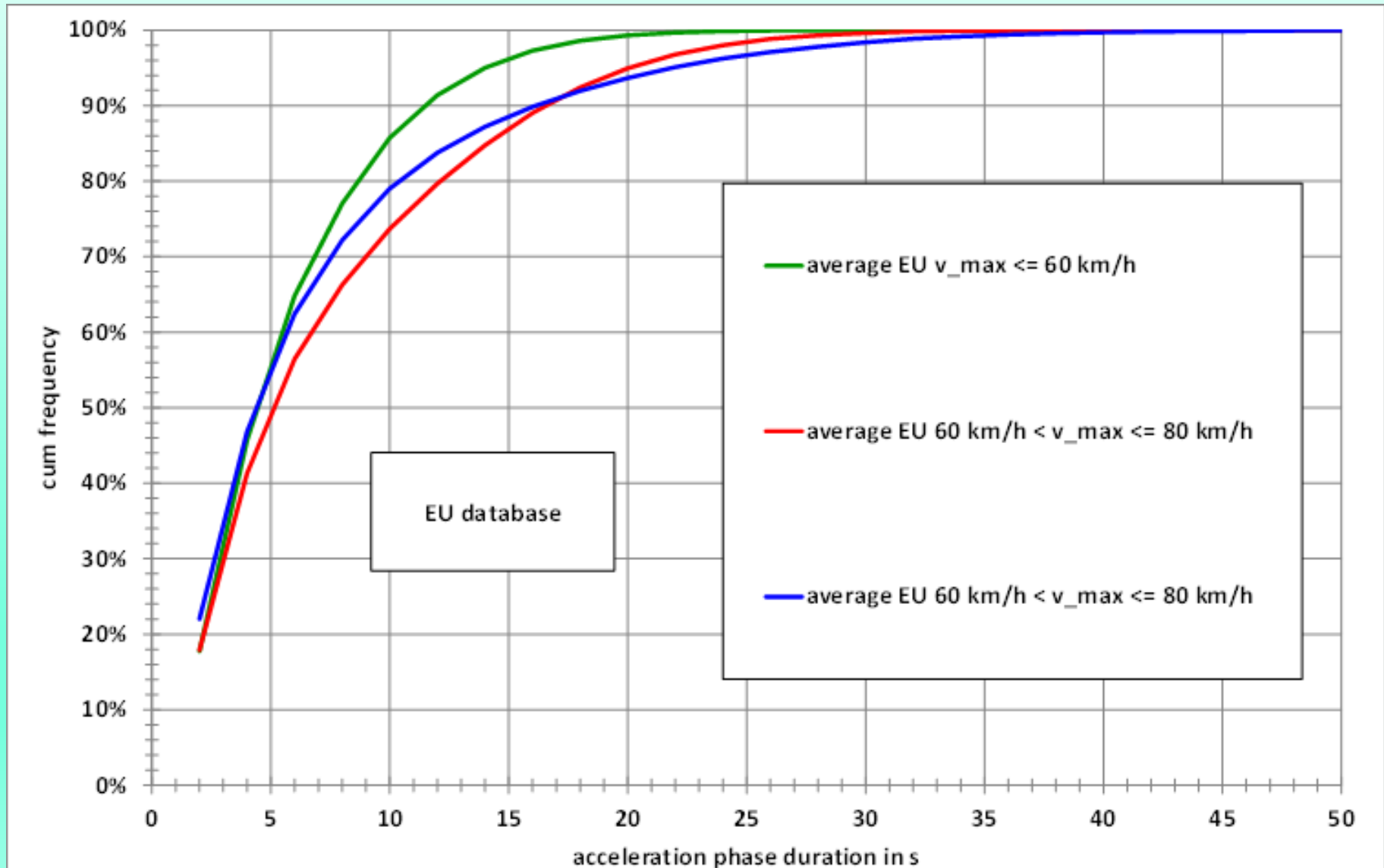
45

Acceleration distributions

Figure 17

Acceleration distributions
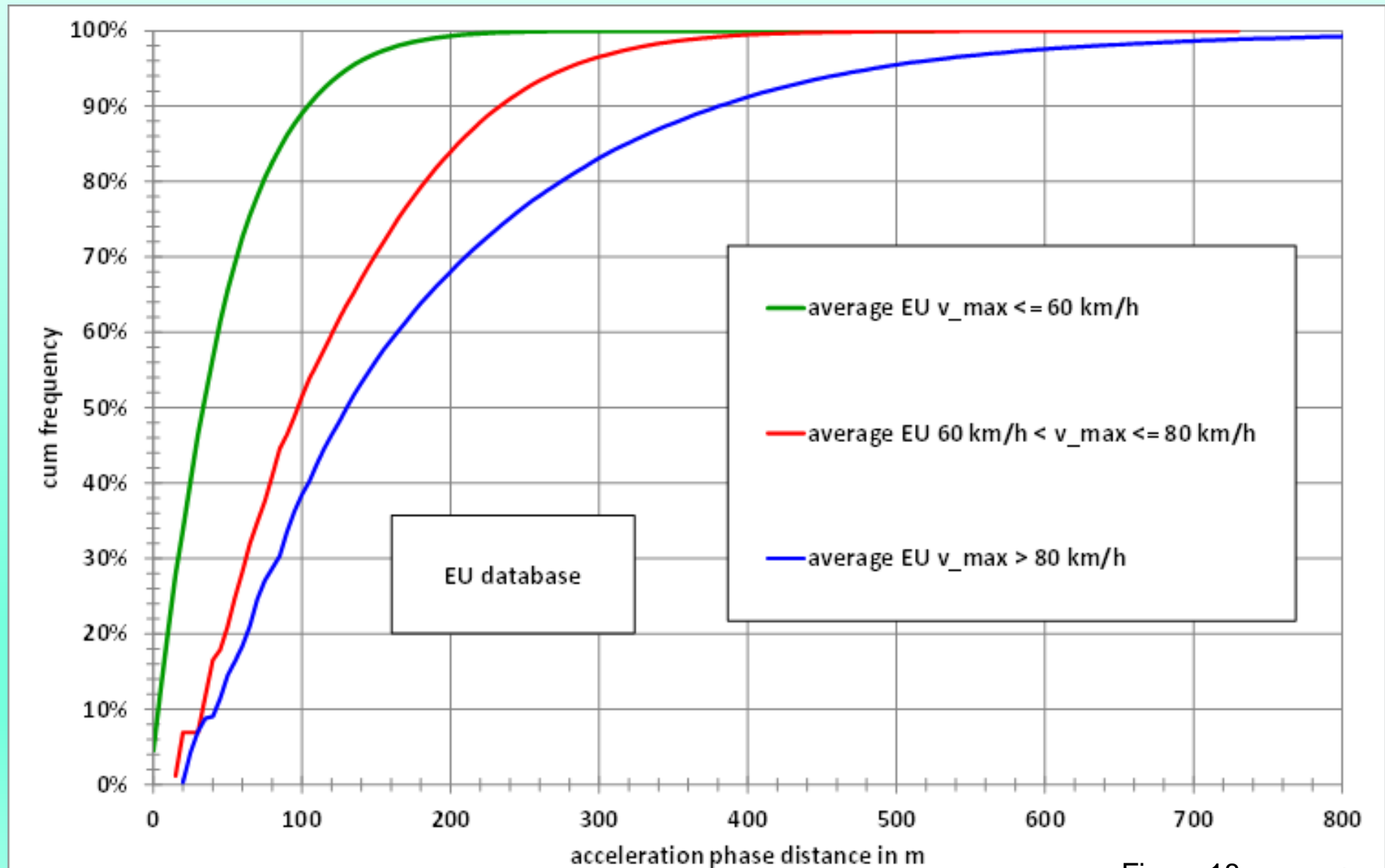

Figure 18

47

Deceleration duration distributions

- **Deceleration phases are specified as consecutive time samples with a < -0.5 km/h/s or -0.1389 m/s². The following key parameters of such phases were collected in a separate table (TB_acc) per vehicle and trip:**

  - **Date, Time, Duration, Distance,**

  - **v_min, v_ave, v_max, $stddev\_v$,**

  - **a_min, a_ave, a_max,**

  - **$v*a\_min$, $v*a\_ave$, $v*a\_max$.**

- **In order to ease the calculation of duration and distance related distributions the results were binned for both values (2 s for the duration and 5 m for the distance). The analysis was performed for v_{max} <= 60 km/h, 60 km/h < v_{max} <= 80 km/h and v_{max} > 80 km/h separately.**

Deceleration duration distributions

- **The following figures show the duration distributions for individual vehicles in Europe and for the different regions for the lowest v_{max} class.**

- **The distributions for the two other vmax classes are shown in the report.**

- **The distance distributions are also included in the report and show similar trends within the three v_{max} classes.**

- **Figure 21 shows the average duration distributions for the EU and the three v_{max} classes.**

- **Figure 22 shows the corresponding results for the average distance distributions.**
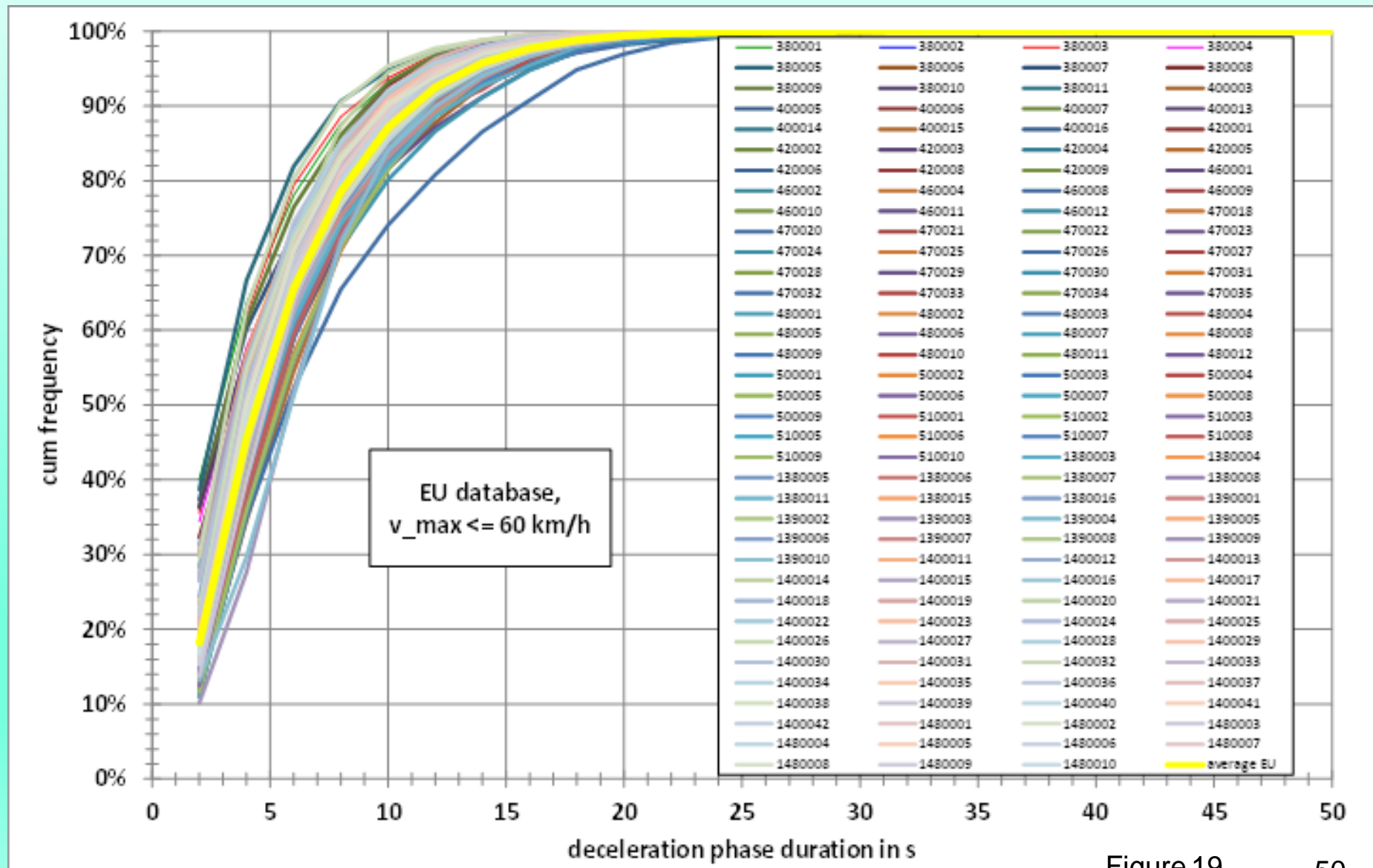
Deceleration distributions
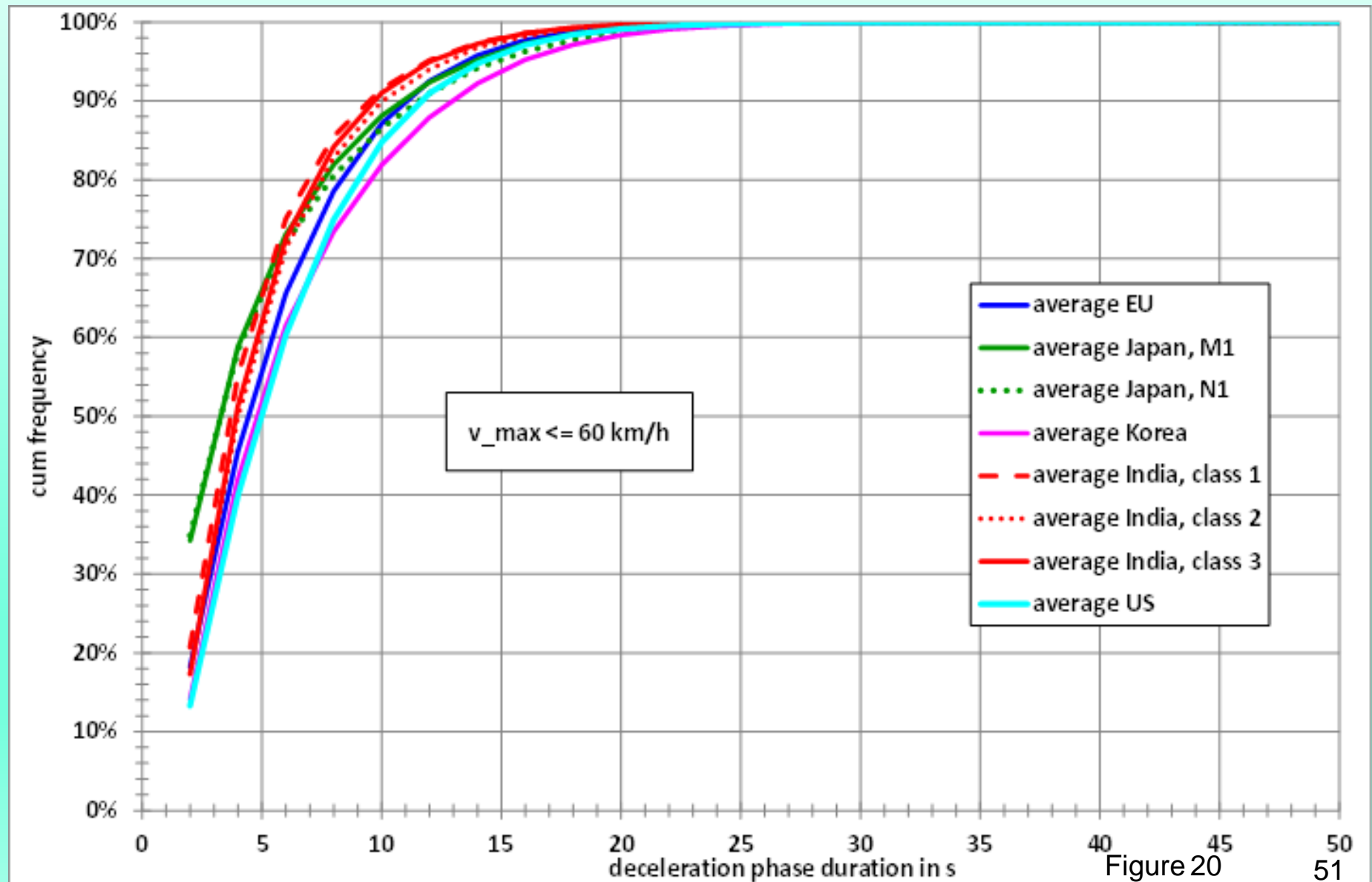

Figure 19

Deceleration distributions

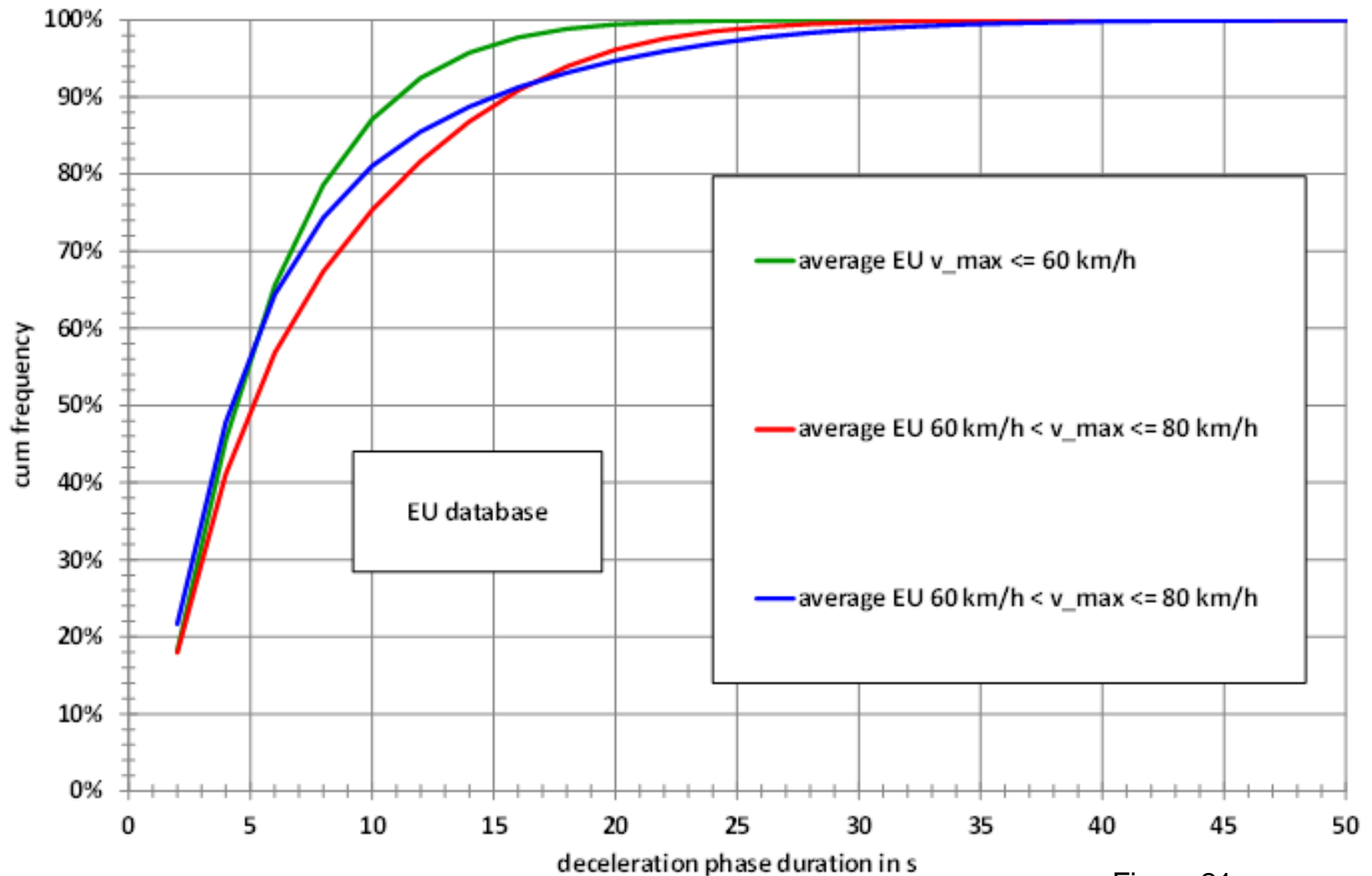Figure 20

Deceleration distributions

Figure 21

52

Deceleration distributions
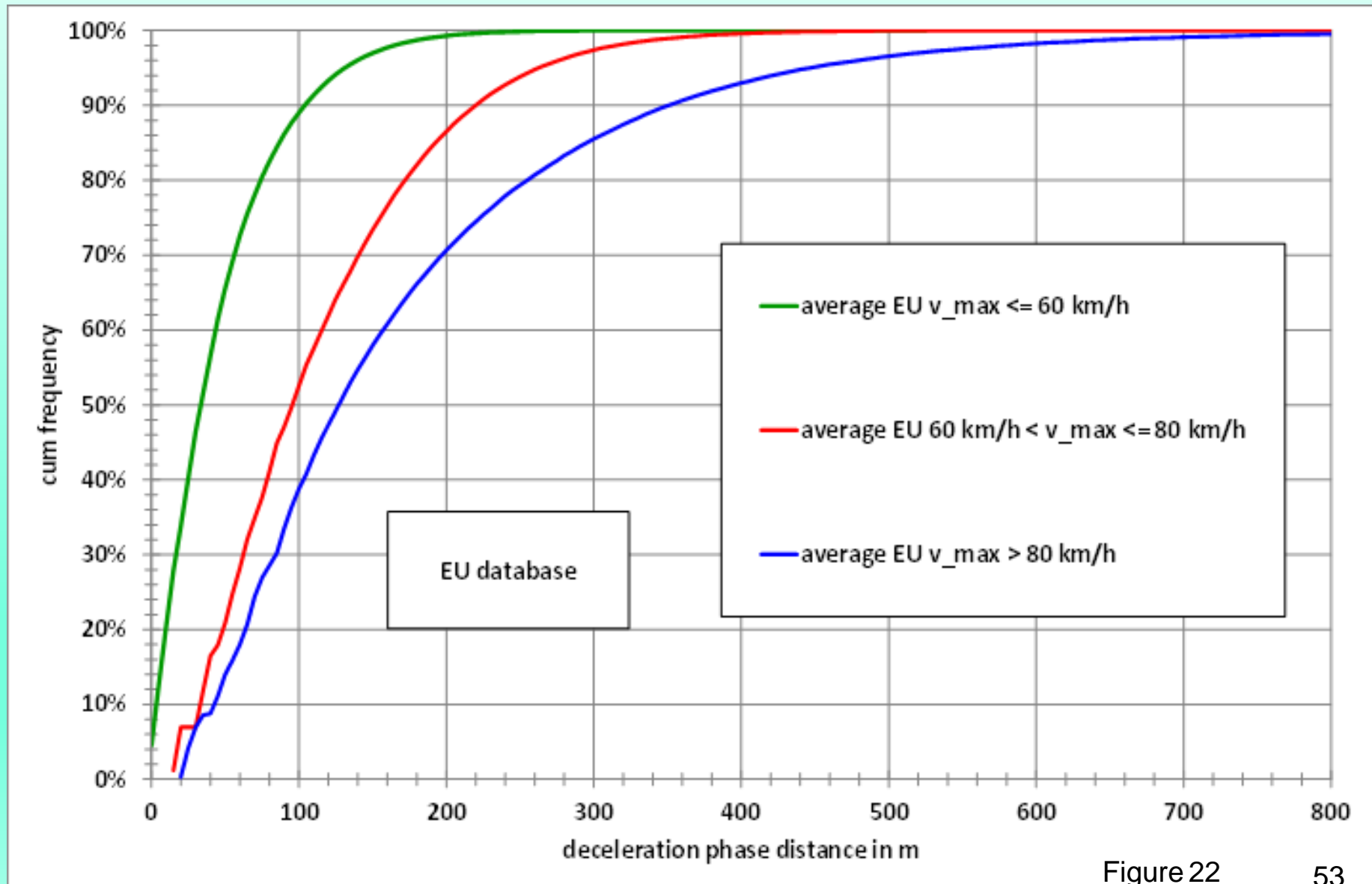
Figure 22

Phases with brake engaged

- **Another task within this analysis was the determination of brake use duration and distance distributions. T**

- **he brake use during deceleration phases should be determined by expert guess thresholds for the deceleration or for v*a respectively.**

- **Fortunately, an alternative method could be used, because the author could analyse in-use driving behaviour data from a former research project of the German Environment Agency, dedicated to the improvement of the type approval noise measurement method for light duty vehicles.**

Phases with brake engaged

- **Within this project in-use driving behaviour measurements were performed with 11 cars in Aachen and the surroundings, where vehicle speed, engine speed and drive axle torque, but also clutch and brake engagement was measured.**

- **Several threshold curves were tested and the resulting brake use duration and distance distributions were compared with the measured ones.**

Phases with brake engaged

- **The best fit was achieved for the following vehicle speed dependent deceleration threshold curve:**

  - $a_{threshold}$ **= -0.098468 * ln(v) - 0.30439**

- **This results in the following polynomial function for a corresponding v*a threshold curve:**

  - **v*$a_{threshold}$ = 7.83392E-07*v^3 - 4.10447E-04*v^2 - 1.80147E-01*v + 3.35105E-01**

- **Both curves are shown in figure 23.**

- **When vehicles with automatic transmissions are disregarded, the calculated distributions are in suffice-ently good agreement with the measured distributions.**

Threshold curves for brake use
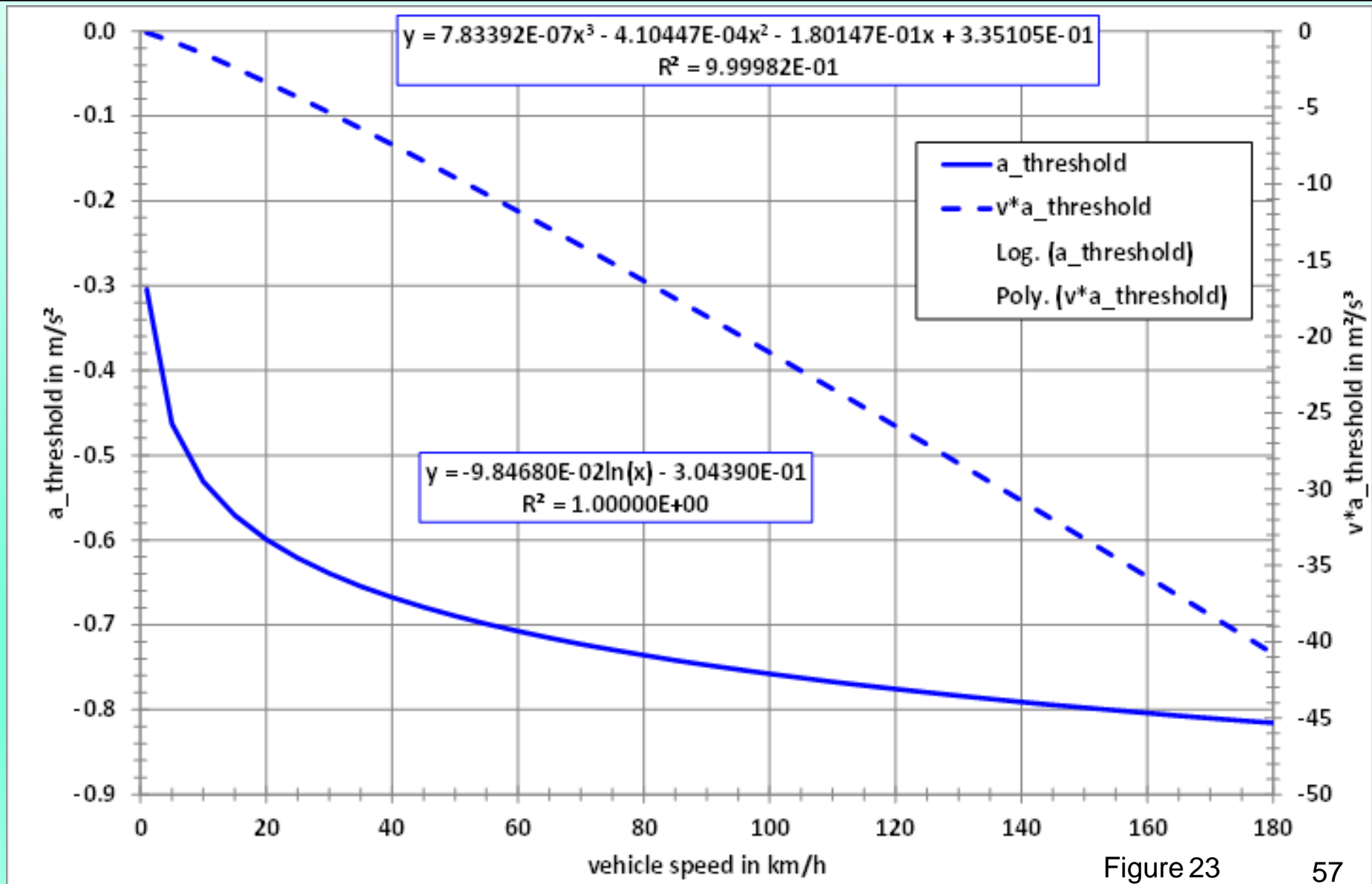
Figure 23

Brake phase duration distribution

- The following figures show the duration distributions for individual vehicles in Europe and for the different regions for the lowest vmax class.

- The distributions for the two other vmax classes are shown in the report.

- The distance distributions are also included in the report and show similar trends within the three vmax classes.

- Figure 26 shows the average duration distributions for the EU and the three vmax classes.

- Figure 27 shows the corresponding results for the average distance distributions.
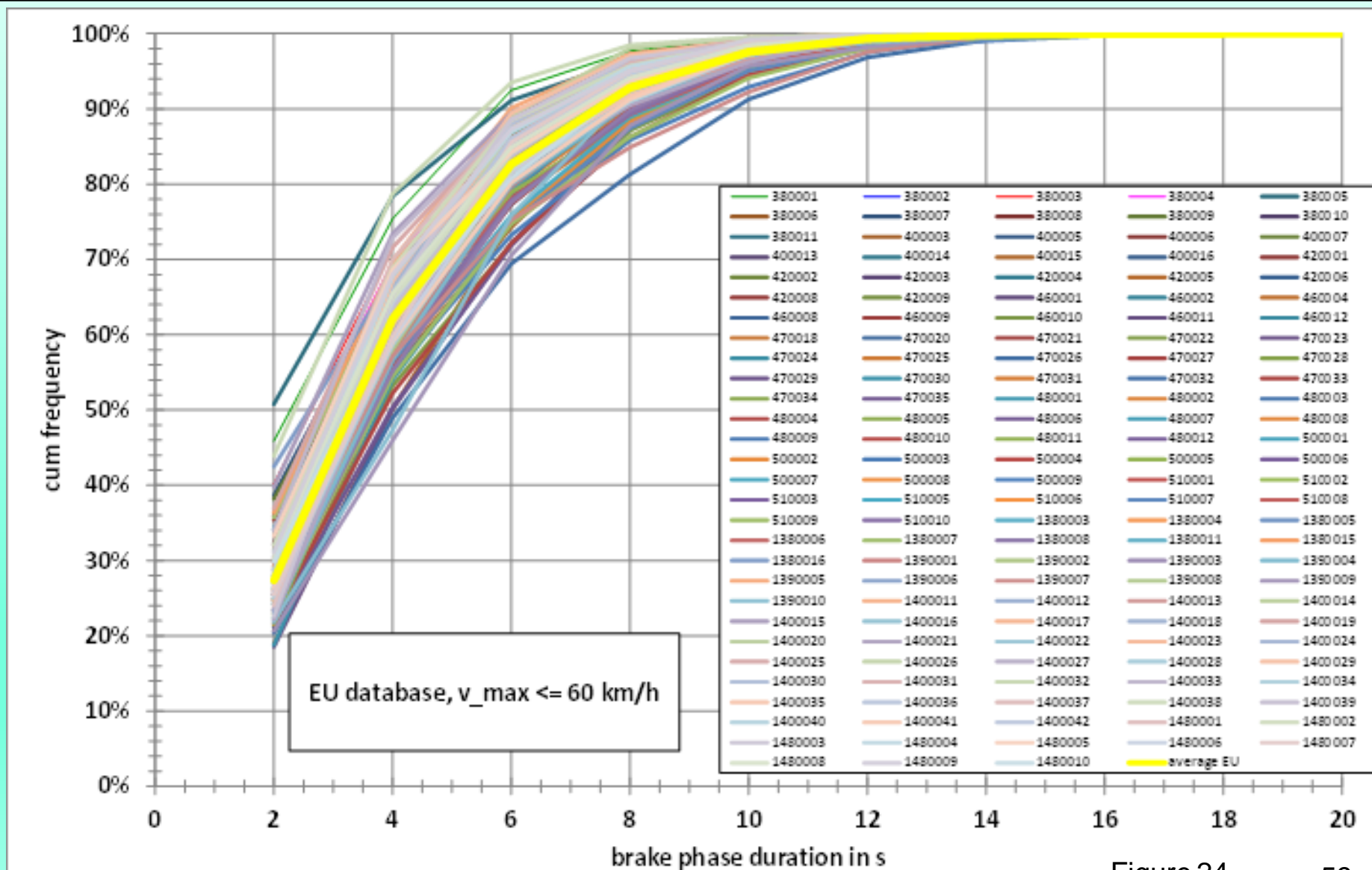
Brake phase distributions

Figure 24
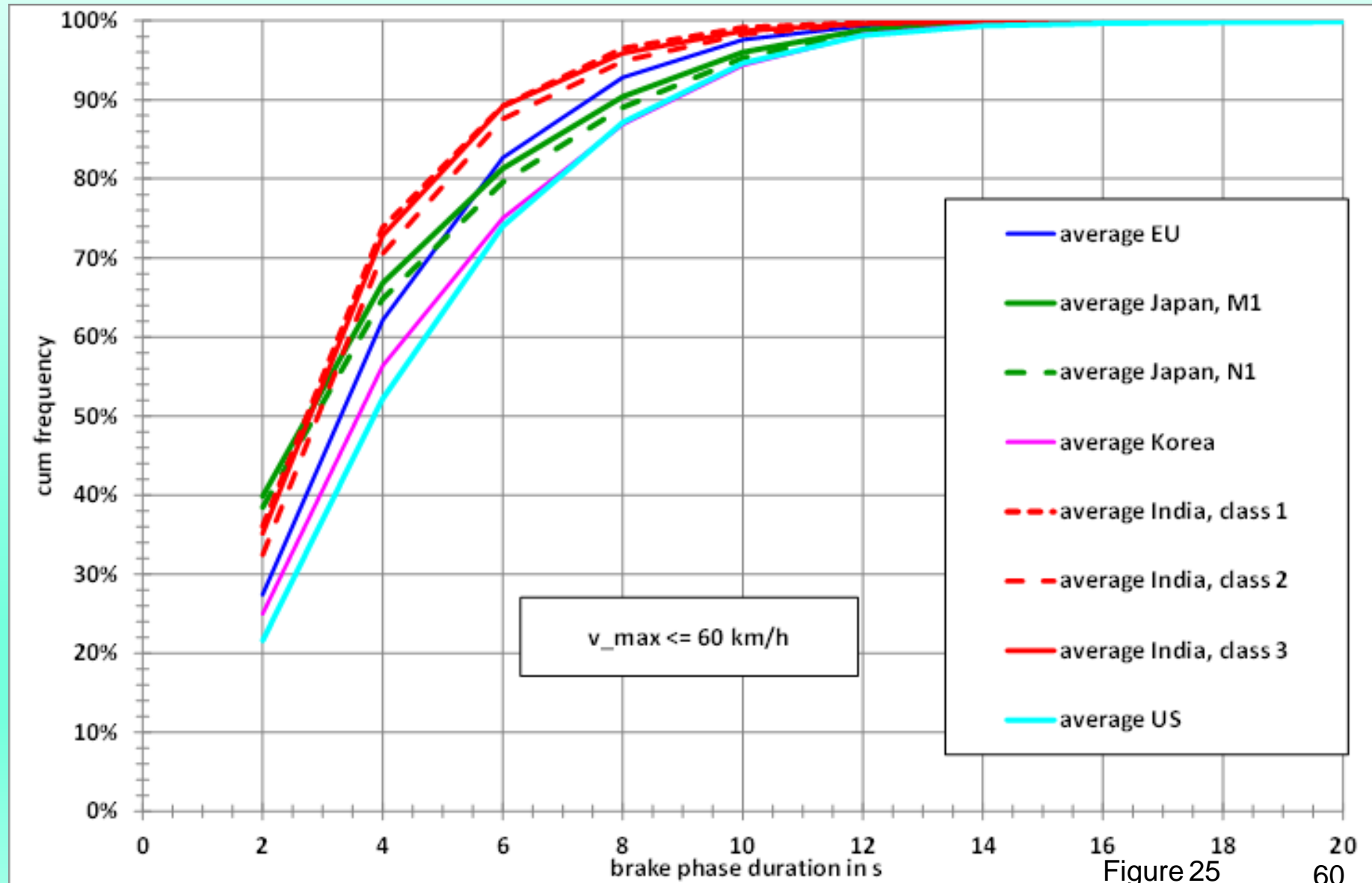
Brake phase distributions
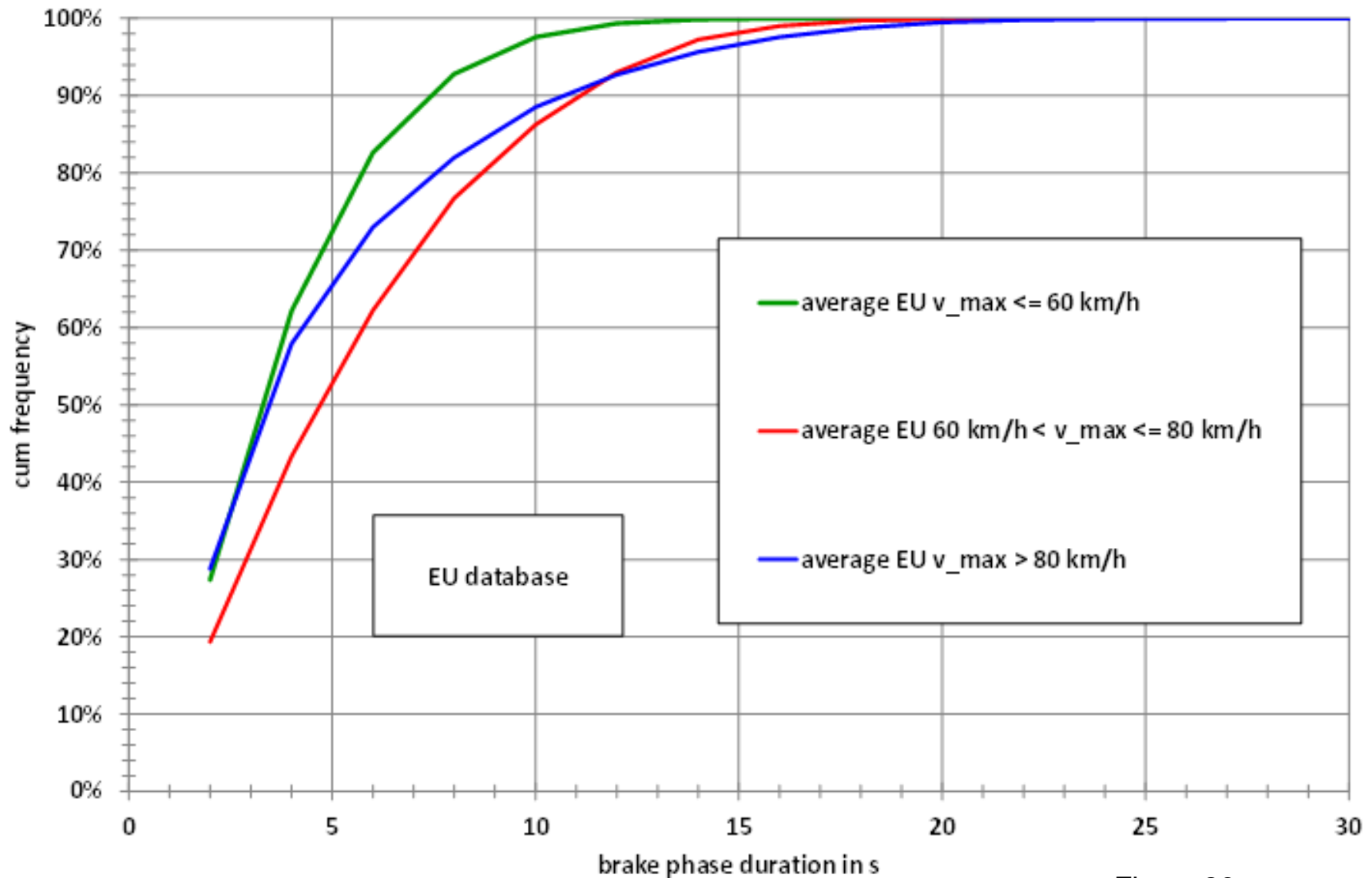

Figure 25

Brake phase distributions

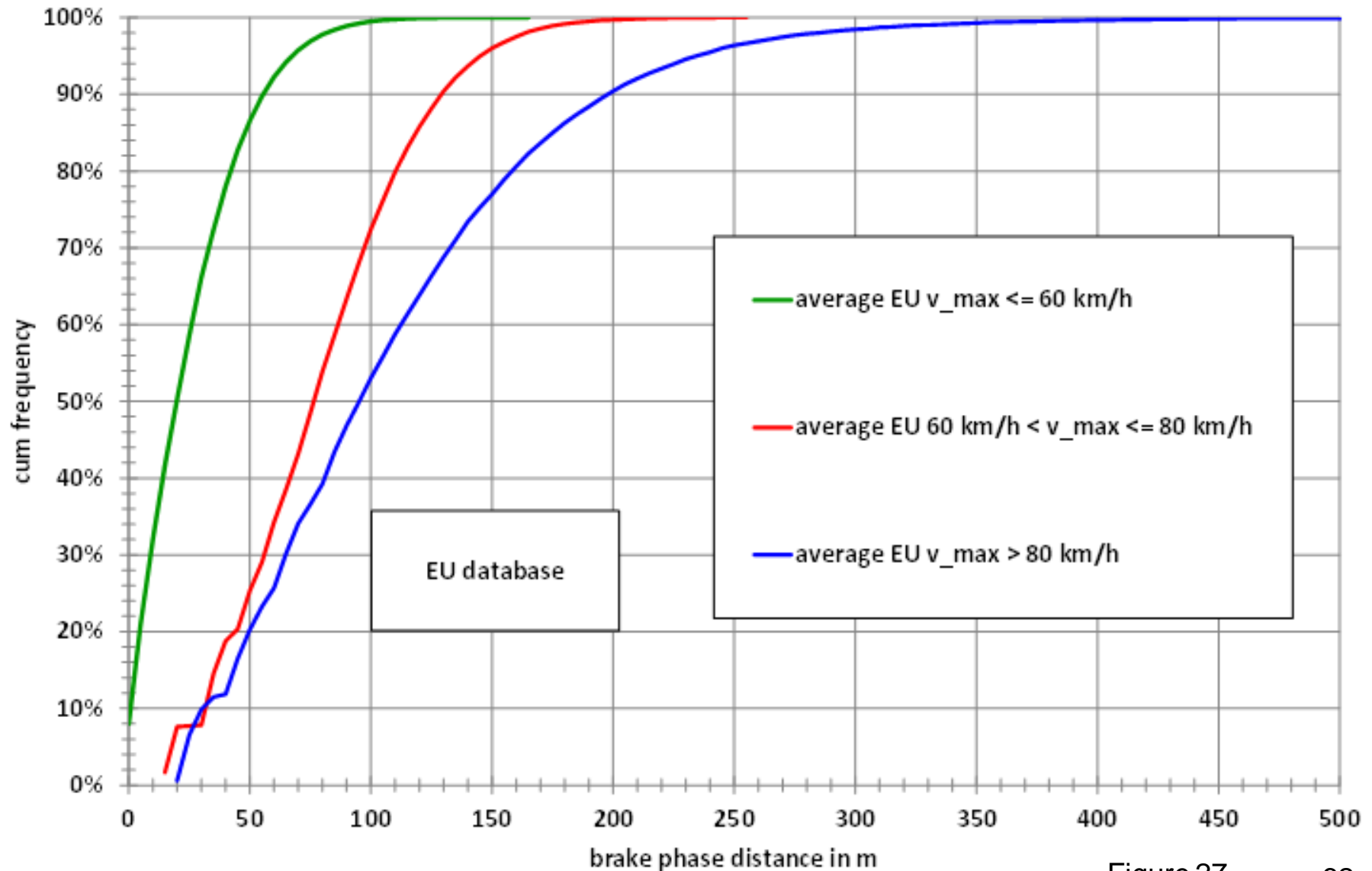
Figure 26

Brake phase distributions

Figure 27

Number of brake phases per km

- **The following table shows the average number of brake phases per kilometer for the different regions and different short trip v_{max} classes and for different road categories.**

- **Tables for individual vehicles are included in the report.**

Number of brake phases per km

region	# of brake phases per km				
	average	Short trips with v_max			
		<= 60 km/h	60 km/h < and <= 80 km/h	80 km/h < and <= 110 km/h	> 110 km/h
Europe	1.56	5.3	2.1	1.0	0.4
India, class 1	1.36	1.7	0.5		
India, class 2	1.55	3.7	1.3	0.8	
India, class 3	1.84	4.4	1.9	1.1	1.1
Japan	3.00	6.1	2.1	0.7	0.4
Korea	2.01	4.3	1.5	0.8	0.7
USA	1.37	6.4	2.4	1.3	0.3

region	# of brake phases per km		
	urban	rural	motorway
Europe	3.8	1.0	0.2
India, class 1	3.2	1.6	
India, class 2	2.3	1.5	0.8
India, class 3	2.8	2.1	1.0
Japan	4.5	1.3	1.2
Korea	3.6	1.4	0.7

Table 2

Joint v, a distributions

- **Joint vehicle speed/acceleration distributions are shown in annex 2 (time weighted) and annex 3 (distance weighted) of the report.**

Acceleration distributions

- **The following figures show acceleration distributions for accelerations > 0.15 m/s² (acceleration bins >= 0.2 m/s², bin distance 0.1 m/s²)**

- **Figure 28: Europe per road category, time weighted,**

- **Figure 29: Europe per vehicle speed bin, time weighted**

- **Figure 30: Europe per vehicle speed bin, distance weighted.**

- **Corresponding figures for the different datasets also from other regions are provided in the report.**

- **Vehicle specific distributions for different speed bins are provided in paragraph 13 of the report for the EU part.**

- **An example is shown in figure 31.**
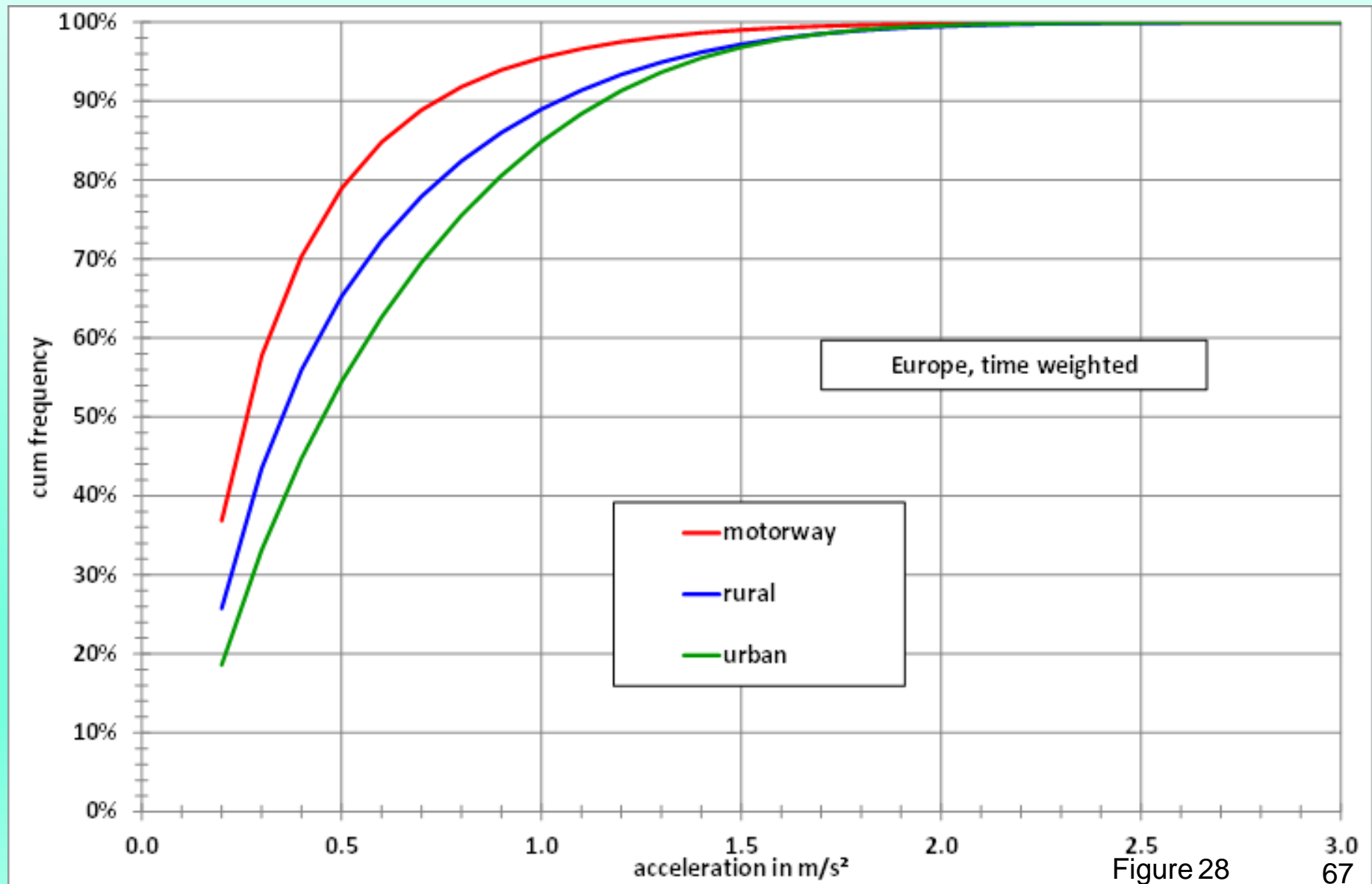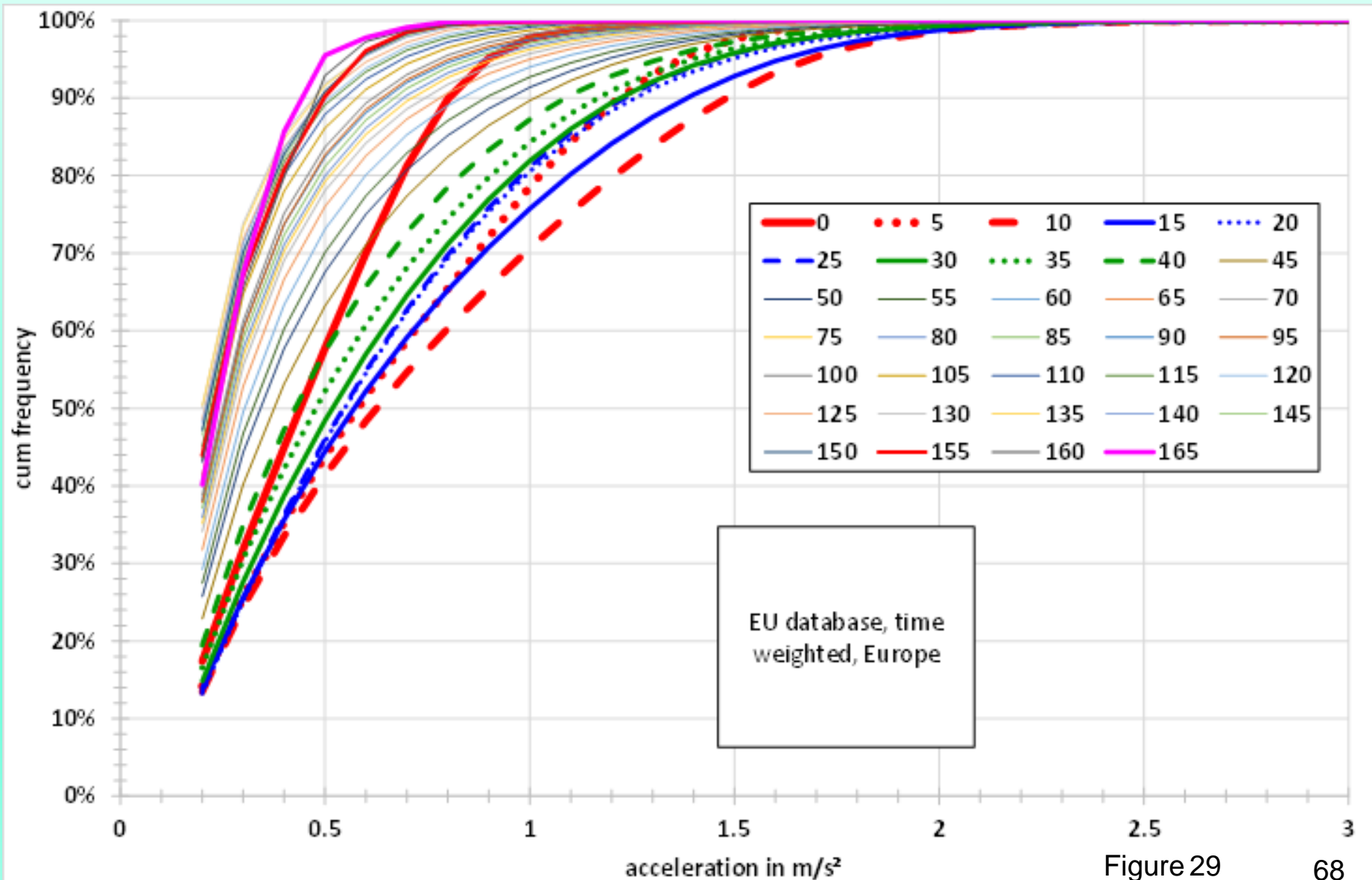
Acceleration distributions

Figure 28

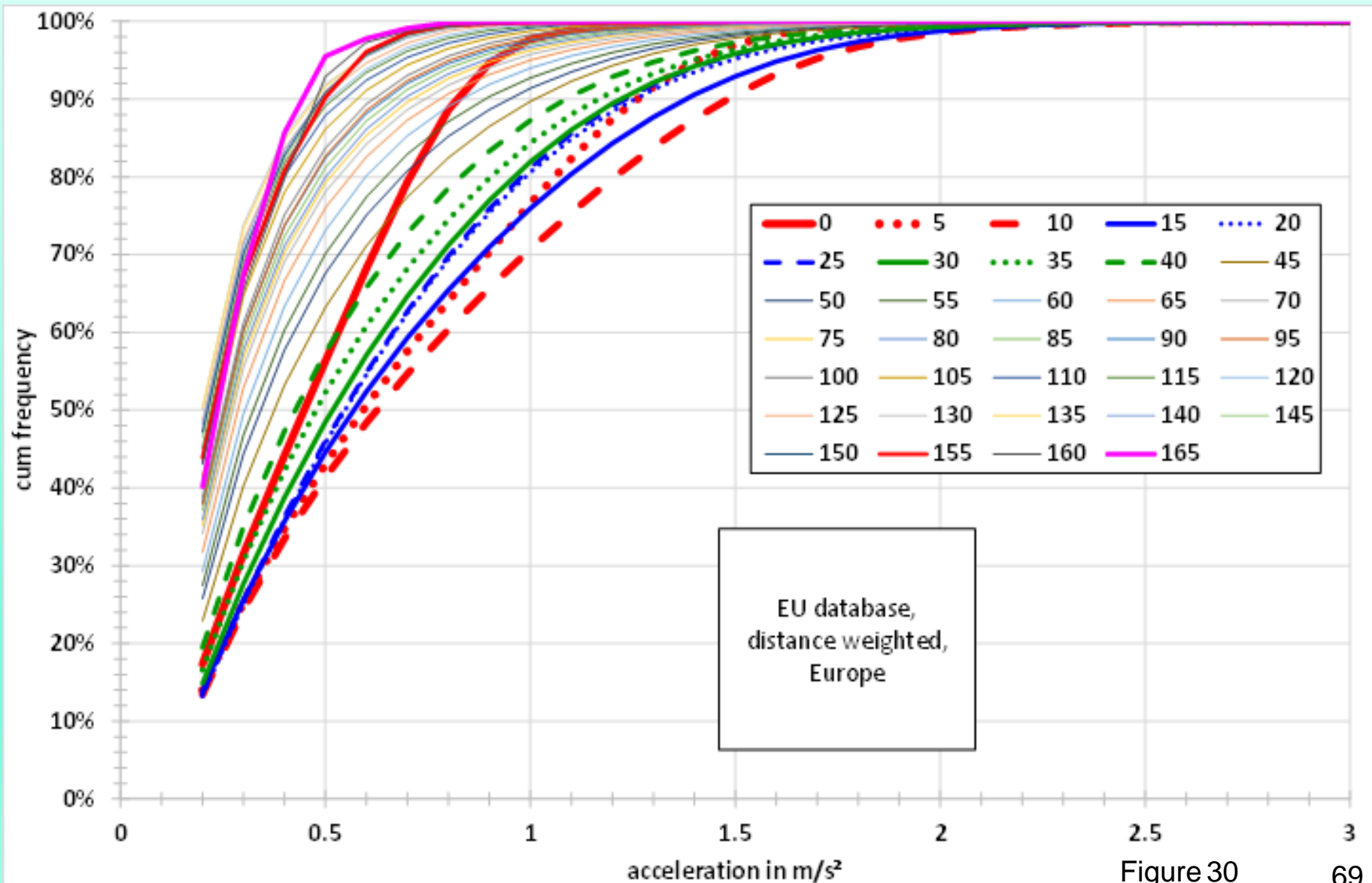# Acceleration distributions

Figure 29

Acceleration distributions

Figure 30
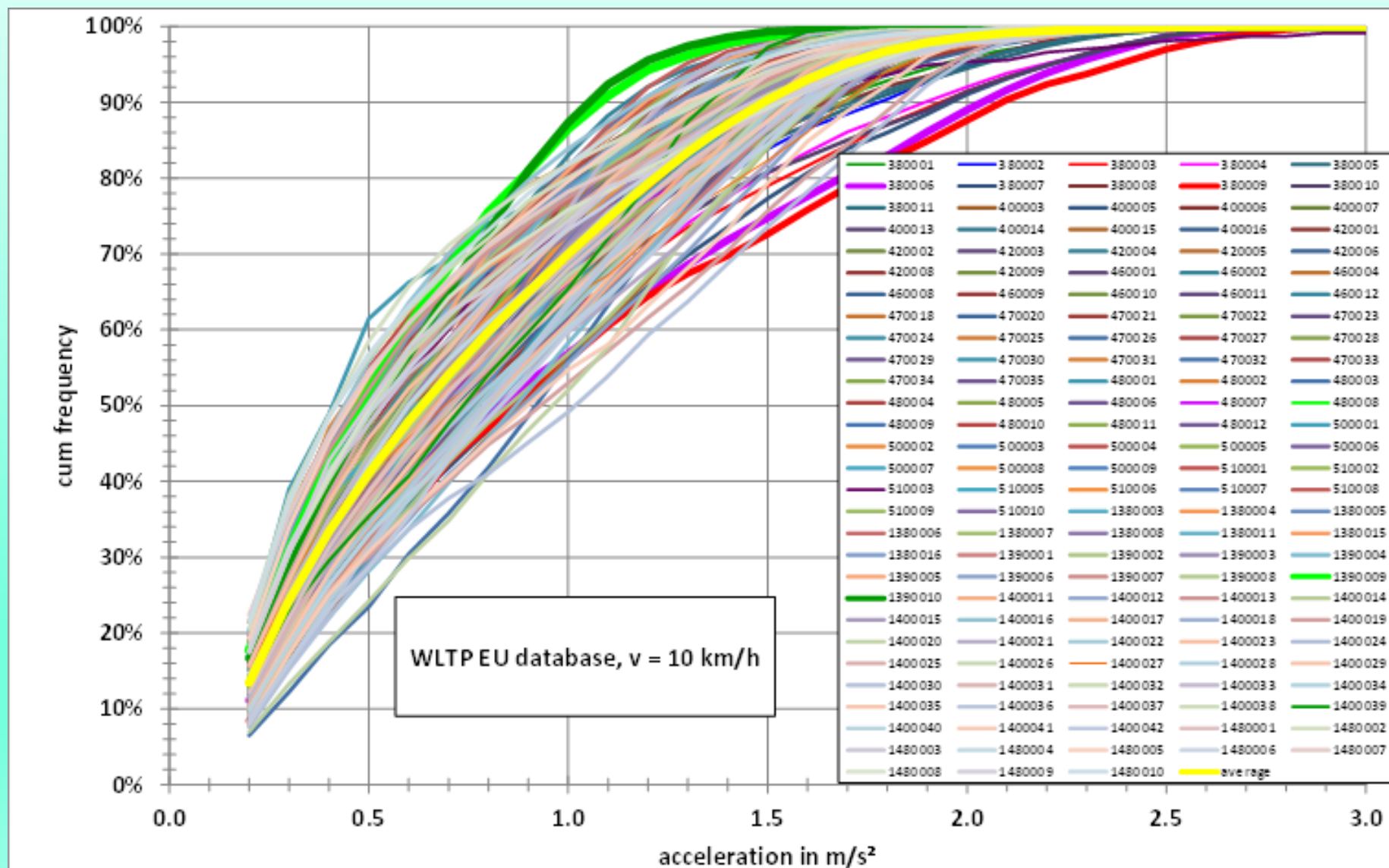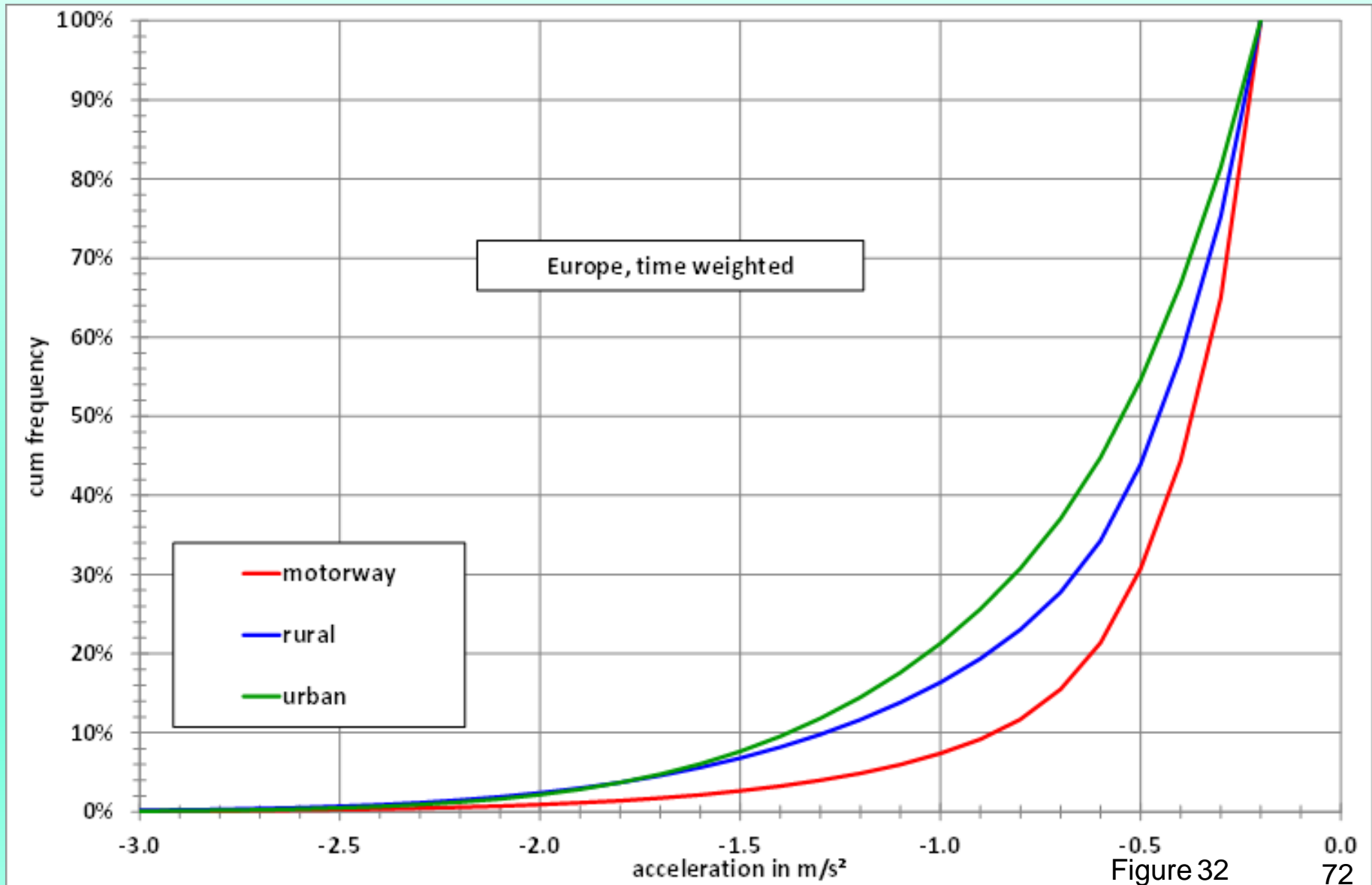
Acceleration distributions

WLTP EU database, v = 10 km/h

Figure 31

Deceleration distributions

- **The following figures show deceleration distributions for accelerations < -0.15 m/s² (acceleration bins <= -0.2 m/s², bin distance 0.1 m/s²)**

- **Figure 32: Europe per road category, time weighted,**

- **Figure 33: Europe per vehicle speed bin, time weighted**

- **Figure 34: Europe per vehicle speed bin, distance weighted.**

- **Corresponding figures for the different datasets also from other regions are provided in the report.**

- **Vehicle specific distributions for different speed bins are provided in paragraph 14 of the report for the EU part.**

- **An example is shown in figure 35.**

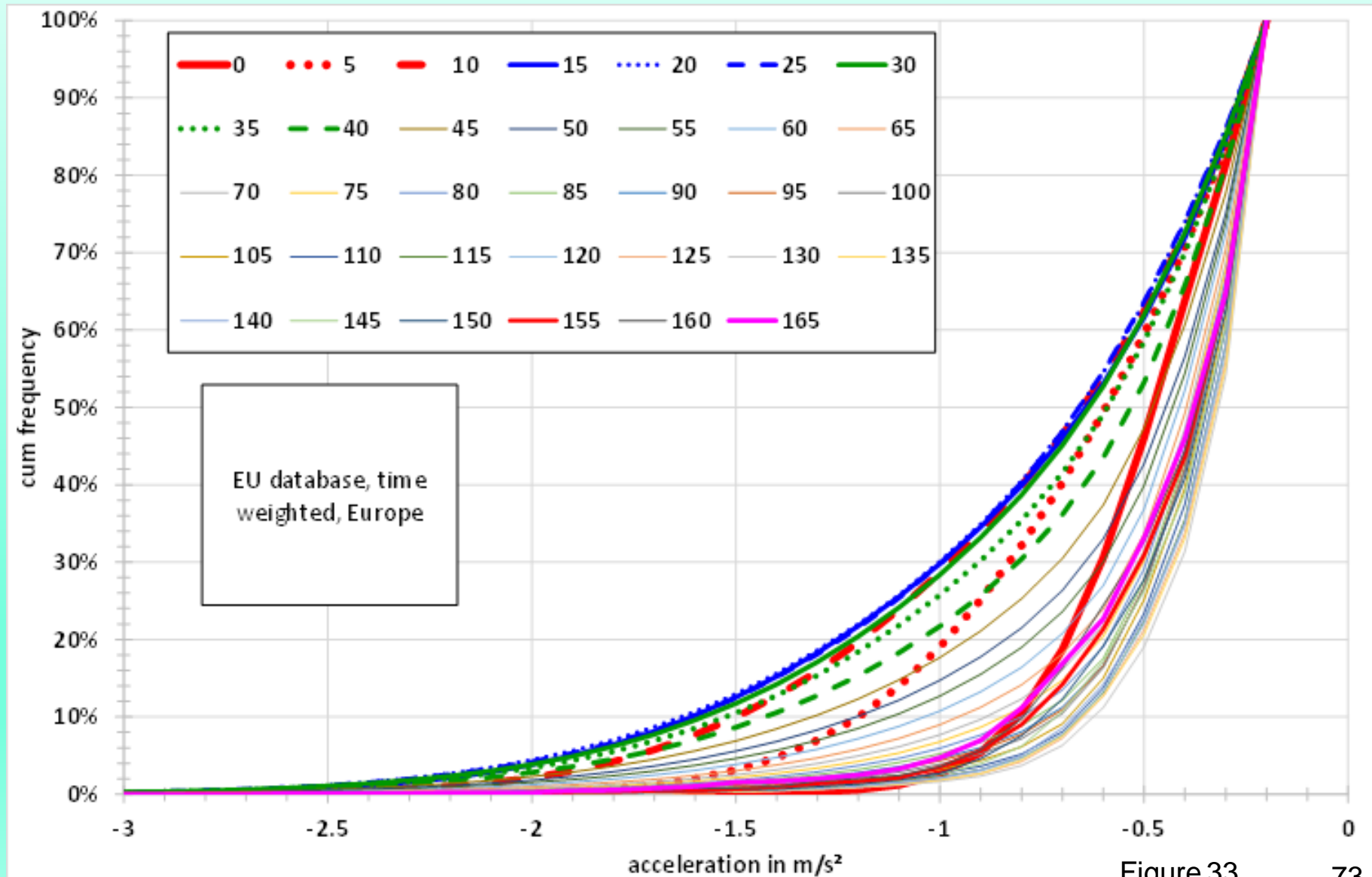# Deleration distributions

Figure 32

Deceleration distributions

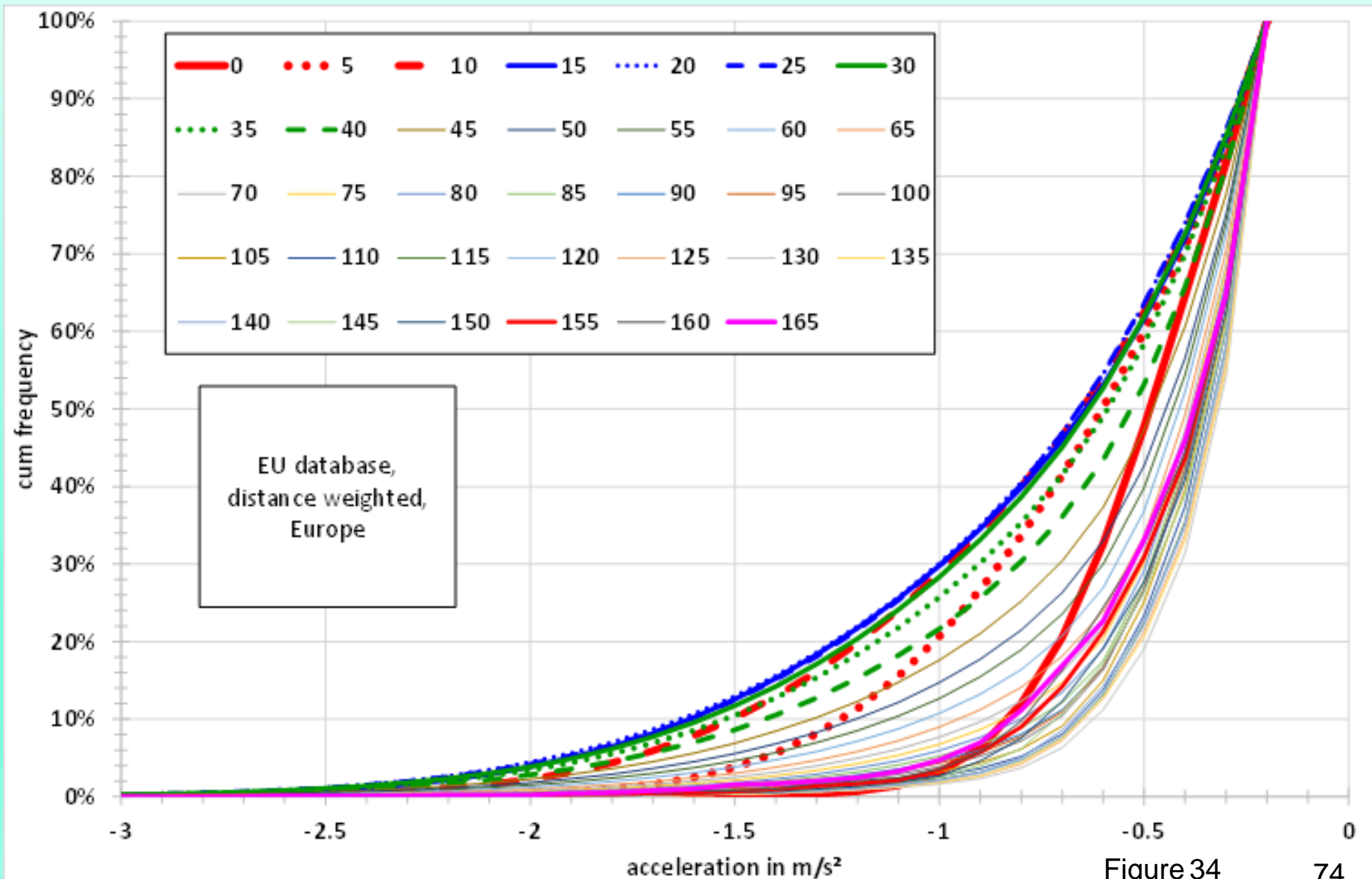EU database, time weighted, Europe

Figure 33

Deceleration distributions

EU database, distance weighted, Europe

Figure 34

Deceleration distributions

WLTP EU database, v = 10 km/h
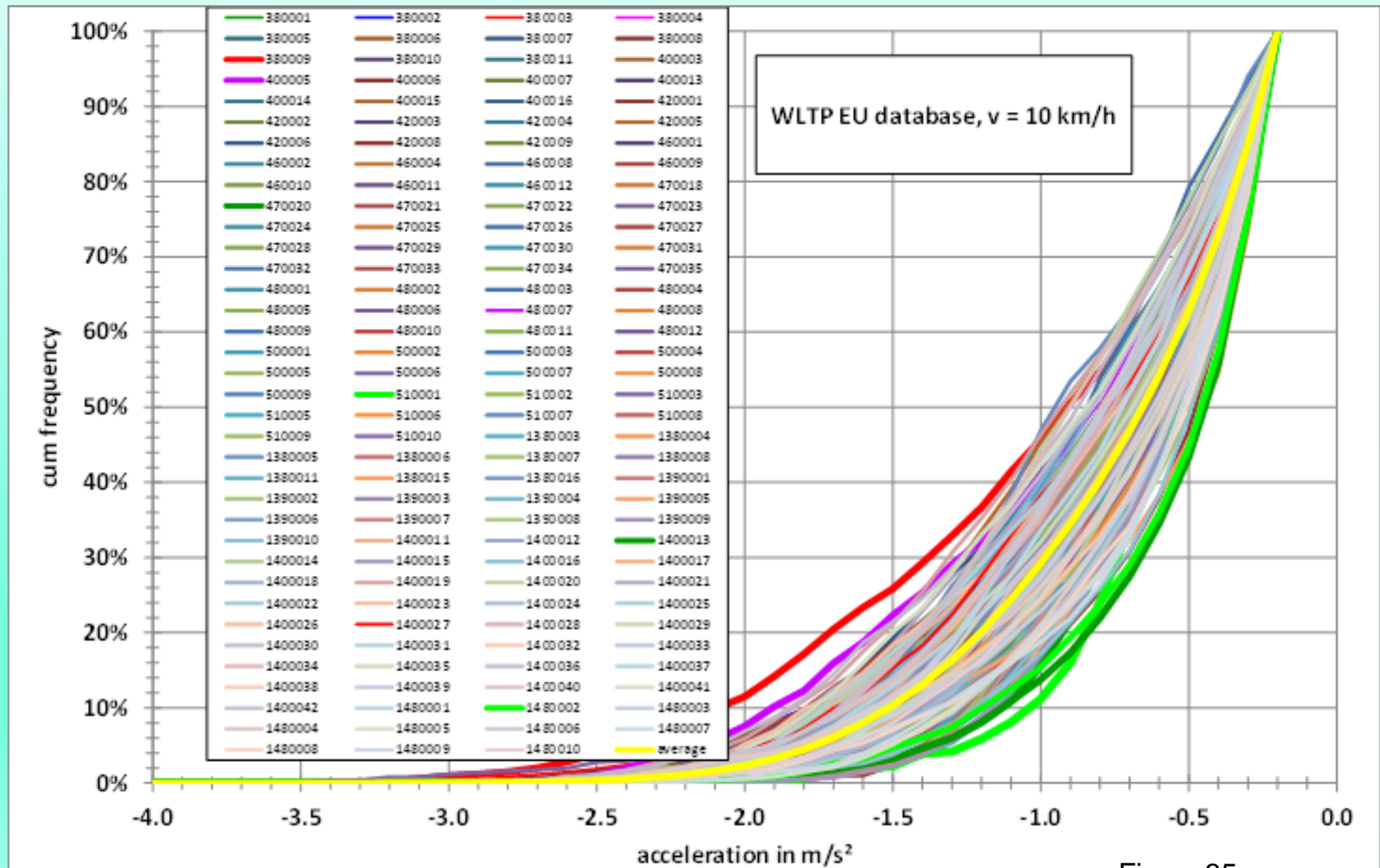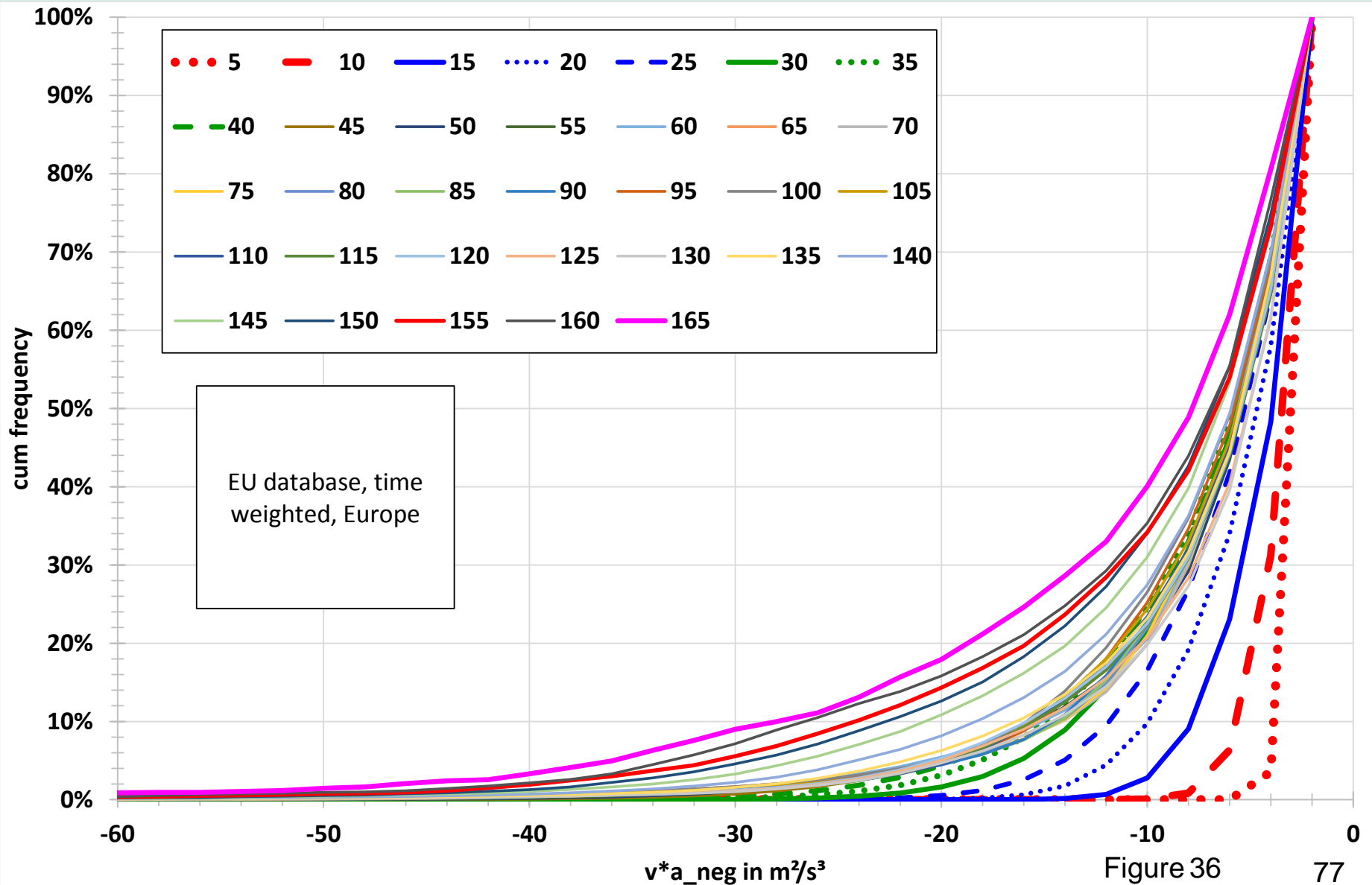
Figure 35

v*a_neg distributions

- **Paragraph 15 of the report contains distributions of v*a for decelerations for v*a < -1 m³/s² in v*a bins of 2 m³/s² distance for different speed bins and datasets in the EU, time and distance weighted.**

- **Figure 36 shows a time weighted example.**

v*a distributions

EU database, time weighted, Europe

Figure 36

End

- **Thank you for your attention**