Developing a new noise calculation method

Task 3: Survey Report

National Highways

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Quality information

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Executive Summary

The Calculation of Road Traffic Noise (CRTN) methodology, used in the United Kingdom (UK), dates back to the 1970s and was last revised in 1988. Whilst it remains capable of meeting the original purpose of supporting the Noise Insulation Regulations and assessing road traffic noise levels under a variety of commonly encountered conditions, it was designed prior to the advent of 3D modelling software and does not account for all scenarios that practitioners would wish to consider in the 21st century.

As such, progress is being made in the development of a new calculation methodology for sound levels outdoors. The new methodology would consider both road and rail noise and as such would also replace the Calculation of Railway Noise (CRN) which dates back to 1995. The new method treats road (and rail) vehicles as equivalent moving sound power levels with a common propagation element. Stakeholder feedback indicated that using the IMAGINE model, developed from measurement programmes completed in mainland Europe between 2000 and 2005, was a suitable foundation for the road noise source terms.

This report describes the measurement programme completed to update and validate the IMAGINE model with respect to its use in determining road vehicle sound power levels as part of the proposed new national methodology for the UK. A companion report presents the resulting road noise source emission method in a format that could form the basis of part of the new standard.

The validation was completed through a series of roadside vehicle noise measurements. Sound power levels for the vehicles were derived from the measured sound pressure levels at the microphone using a short-range point-to-point implementation of the IMAGINE propagation method. The validation programme considered the key parameters governing the road vehicle source noise such as the vehicle class and speed, and the road surface. Other parameters, such as vehicle acceleration were not validated directly but reviewed in the context of the use of the new calculation method and the development of the IMAGINE method.

It is anticipated that alongside the new national calculation methodology, guidance documents concerning use of the standard will need to be updated or created as required depending on the application of the method. Such guidance would likely include a discussion on the uncertainty inherent in the model.

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1. Introduction

1.1 Background

The Calculation of Road Traffic Noise (CRTN) methodology (REF 1), used in the United Kingdom (UK), dates back to the 1970s and was last revised in 1988. Whilst it remains capable of meeting the original purpose of supporting the Noise Insulation Regulations (REF 2) and assessing road traffic noise levels under a variety of commonly encountered conditions, it was designed prior to the advent of 3D modelling software, and does not account for all scenarios that practitioners would wish to consider in the 21st century.

As such, development of a new calculation methodology has been discussed within the British Standards EH/1/2 Committee on transportation noise. A scoping panel was created to look into what would be required of a new calculation method. This panel produced a number of scoping documents outlining the key stakeholders, user requirements and a suggested format for a new method covering both road and rail noise sources, and their propagation (REF 3, REF 4).

The approach outlined in the scoping documents consists of treating road and rail vehicles as equivalent moving sound power levels with a common propagation element. This is the approach taken in many European calculation methods, including the CNOSSOS-EU methodology described in Directive 2015/996 (REF 5) and subsequently updated in Delegated Directive 2021/1226 (REF 6). However, as the CNOSSOS-EU methodology has been designed and validated only for strategic scale national mapping, it is not considered appropriate to adopt it as a national standard which must be capable of modelling localised effects.

Following these scoping documents, working groups on each technical part of the proposed method were created with the aim of deciding upon the approach, and work required to finalise each part of the method (propagation, road sources and rail sources).

Feedback from discussions amongst the working group on road traffic noise, together with responses from the acoustics community, indicated that using the IMAGINE model (REF 7) as a foundation for the road noise source terms was the preferred approach. The IMAGINE model follows the overarching approach adopted by CNOSSOS-EU but is more flexible, making it more applicable to local scale traffic noise calculations.

However, the IMAGINE model was developed from measurement programmes completed in mainland Europe between 2000 and 2005, and therefore requires validation with respect to its use as a national methodology for the UK going forwards. The aim of this programme of work for National Highways is to validate the IMAGINE source noise terms, described in (REF 8), relating to the vehicle fleet and road surfaces in UK in 2023/2024. The project tasks are described in Section 1.2.

The validation may be completed through a series of roadside vehicle noise measurements, if the sound power level at source can be calculated from the measured roadside sound pressure level. Performing this calculation makes use of the propagation element of the proposed new calculation method. Therefore, work is required to determine the propagation method and implement it, in a point-to-point fashion over a relatively short range, to support the validation exercise. This work, using the IMAGINE sound propagation model (REF 9), was commissioned by Defra, and the outcomes support the analysis task within this programme.

1.2 Project scope

The validation exercise for the road traffic source noise terms is broken down into four tasks as follows:

- Task 1: Inception meeting
- Task 2: Establish gaps in vehicle noise emission data
- Task 3: Undertake a suite of statistical pass-by noise measurements in order to obtain relevant data for use within the proposed new road calculation methodology/standard

- Task 4: Implementation - complete part 4 (road source terms) of the proposed standard

This report summarises the work completed under Task 3. It outlines the methodology for the vehicle noise data collection, including details of the surveys carried out at each location. The results obtained from these surveys and subsequent analysis is presented, alongside details of the type of road surface. For locations on the Strategic Network (SRN) road surface information was obtained from the National Highways Pavement Asset Management System (PAMS) database. For other locations the road surface type and age were estimated from close-up photographs of the surface layer.

Task 2 is reported in (REF 10) and Task 4 is reported as a draft standard describing the new methodology in (REF 11).

2. Survey programme

This section presents the data collection methodology as well as details of the surveys carried out.

2.1 Data collection methodology

As part of this programme of work, data from 56 survey locations were analysed. These were made up of noise measurements of vehicles at 47 sites across England in 2023/24, covering 10 different road surface types, supplemented by data from 9 further sites measured between 18th and 23rd March 2021 as part of a study for National Highways to understand the impact the COVID-19 lockdowns had on road traffic noise.

One-third octave band frequency data relating to the A-weighted maximum noise level from vehicle pass-bys were captured using a sound level meter with a microphone placed upon a tripod. The speed of the vehicle was also captured using a handheld speed gun. The methodology of these surveys closely followed the Statistical Pass-By (SPB) methodology outlined in ISO 11819-1 (REF 12). This methodology is used for the Highways Authority Product Approval Scheme (HAPAS) to calculate the acoustic performance of road surfaces in terms of the Road Surface Influence (RSI) (REF 13). Further details on the SPB methodology and the associated calculated RSI values can be found in Appendix A.

The SPB methodology requires that the microphone be positioned 7.5 m away from the centreline of the nearest carriageway (e.g. if a two-lane dual carriageway the nearside lane). However, site restrictions meant that for these surveys this was not always possible. The exact measurement position was recorded for each survey location and this value was used to correct the measured values to a theoretical distance of 7.5 m from the carriageway centreline for analysis purposes; see Section 4.1 for further details. The height of the measurement position was set to 1.2 m above the level of the adjacent road surface.

Further data captured during the surveys included the wind speed, road surface temperature and air temperature which were captured at the start and end of every survey as well as at 15-minute intervals throughout the survey. Additionally, the angle of the speed gun to oncoming traffic, and the category of the measured vehicle were also captured. The speed gun angle was used to correct the measured vehicle speed to the speed in the direction of travel of the vehicle. Additionally, a GoPro was set up during the measurements to capture video and audio.

A total of 17 vehicle sub-categories were used for this study to allow for a detailed analysis of the noise level of different vehicle groups. This information was used to help determine whether some vehicle categories warranted their own vehicle class; see Section 4.3 for further details. This expands upon the standard SPB vehicle categories of L for light vehicles, H1 for 2-axle lorries greater than 3.5 tonnes and H2 for lorries greater than 3.5 tonnes with more than 2-axles. The vehicle sub-categories used are shown in Table 1.

Table 1: Vehicle sub-categories

Vehicle code	Description
L1	Small / standard car
L1_V	Car derived van
L1_E	Small / standard car – electric
L1_V_E	Car derived van – electric
L2	Large family car
L2_V	Medium sized van (e.g. Ford Transit)
L2_E	Large family car – electric
L2_V_E	Medium sized van – electric
L3	Sports car

Vehicle code	Description
H1	2 axle lorry
H1_V	Box van
H1_C	Coach
H1_B1	Single decker bus
H1_B1_E	Single decker bus – electric
H1_B2	Double decker bus
H1_B2_E	Double decker bus – electric
H2_N	>= 3 axle lorry (N number of axles)

The 10 identified road surfaces are described in Table 2. The shorthand code adopted for this study has been chosen to match that used for Round 4 Environmental Noise Mapping using the CNOSSOS-EU method (REF 14, REF 5, REF 6).

Table 2: Surface descriptions and shorthand codes

Description	Code
Surface dressing	C02
Concrete (brushed)	C03
TSCS# 6 mm	C04
TSCS 10 mm	C05
TSCS 14 mm	C06
TSCS unknown chip size	C07
Stone mastic asphalt 10 mm	C09
Stone mastic asphalt 14 mm	C10
Hot rolled asphalt 20 mm	C13
Hot rolled asphalt 14mm	C13.2*

TSCS stands for Thin Surface Course System and is defined in National Highways Design Manual for Roads and Bridges (REF 16). The associated number refers to the primary aggregate size in the asphalt mixture

*Surface type code created for this study

2.2 Survey sites

Survey sites consisted of both local authority roads, to capture low speed data, and roads on the SRN, to capture high speed data, and to help determine road surface performance characteristics.

Sites were selected to consist of a range of different surface types of different ages. For locations on the SRN, National Highways' PAMS data were used to find locations adjacent to the road surfaces most commonly found across the network. A map of survey locations is shown in Figure 1 and a typical site set-up is shown in Figure 2. Full details on all survey sites, including the road surface type, speed limit of the road, weather data and equipment used, are provided in Appendix B.

Figure 1: Map of monitoring locations

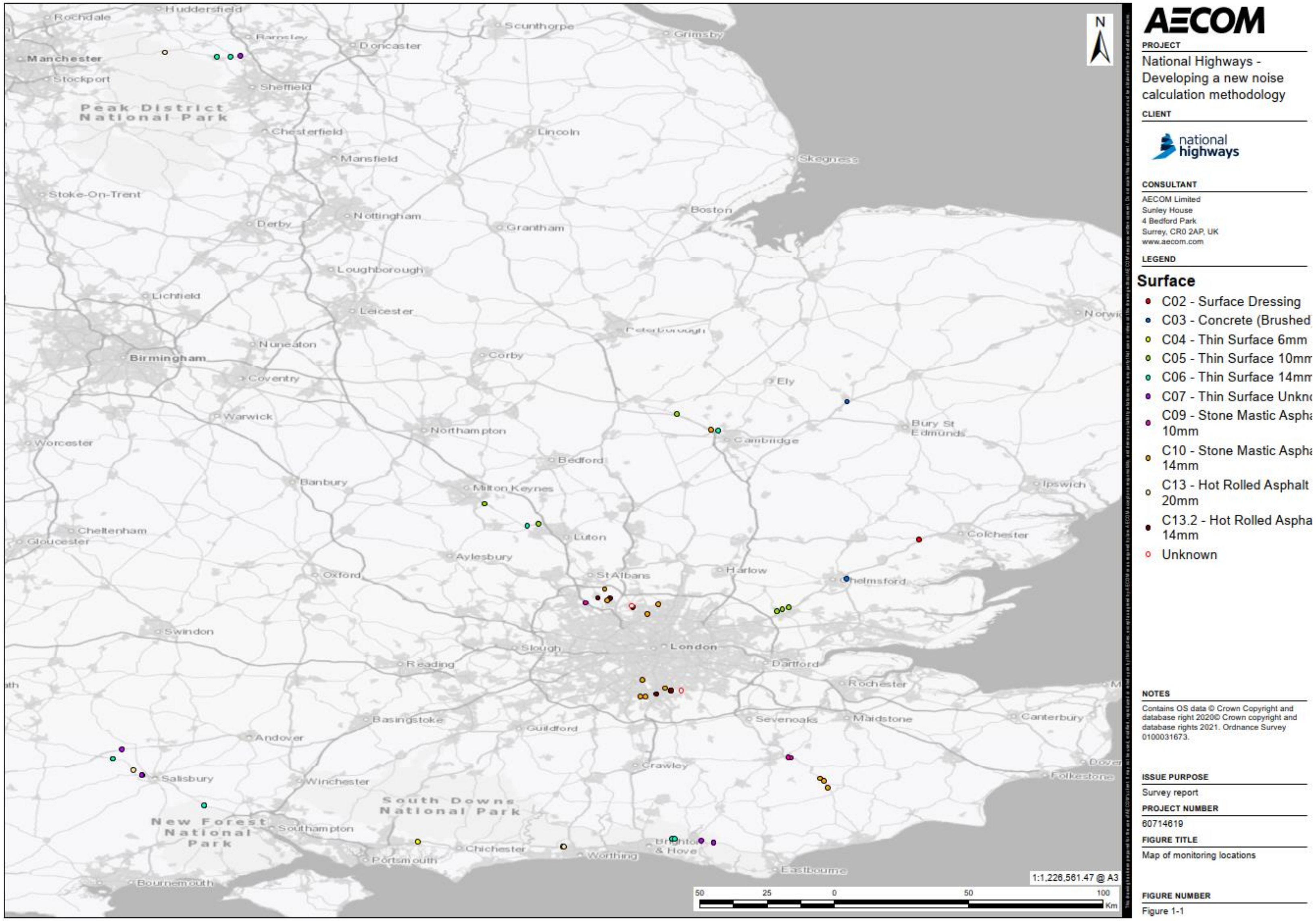


Figure 2: Example of a survey location (O-60-N1)

A summary of surface types captured along with the number of sites, the age range of the surfaces and the speed range of the roads is shown in Table 3.

Table 3: Surface types with total number of sites, age range and speed range

Description	Code	Total sites	Surface age (years)	Speed limit (mph)
Surface dressing	C02	1	26	70
Concrete (brushed)	C03	2	33 & 42	70
TSCS 6mm	C04	1	1	70
TSCS 10mm	C05	6	1, 6 & 8	70
TSCS 14mm	C06	10	3,7,9 & 10	60 & 70
TSCS unknown chip size	C07	8	9,11 & 15	50, 60 & 70
Stone mastic asphalt 10mm*	C09	5	1-2* ,2 ,2-5* & 5	30, 40, 60 & 70
Stone mastic asphalt 14mm*	C10	12	1, 1-2*, 2-5*, 3, >5*, 6 & 8	20, 30, 40, 50, 60 & 70
Hot rolled asphalt -20mm	C13	4	4, 5 & 7	60 & 70
Hot rolled asphalt – 14mm*	C13.2	5	1-2*, >5*	20, 30 & 40
Unknown	N/A	2	Unknown	20

* Sites with this symbol in both the description and surface age columns have had both the surface type and age estimated using site photographs of the surface and not using PAMS data

Figure 3 shows the breakdown of survey sites by surface type. An analysis of the PAMS data indicates that this is a good correlation with breakdown of road surface types found on the SRN.

Figure 3: Breakdown of sites by surface type

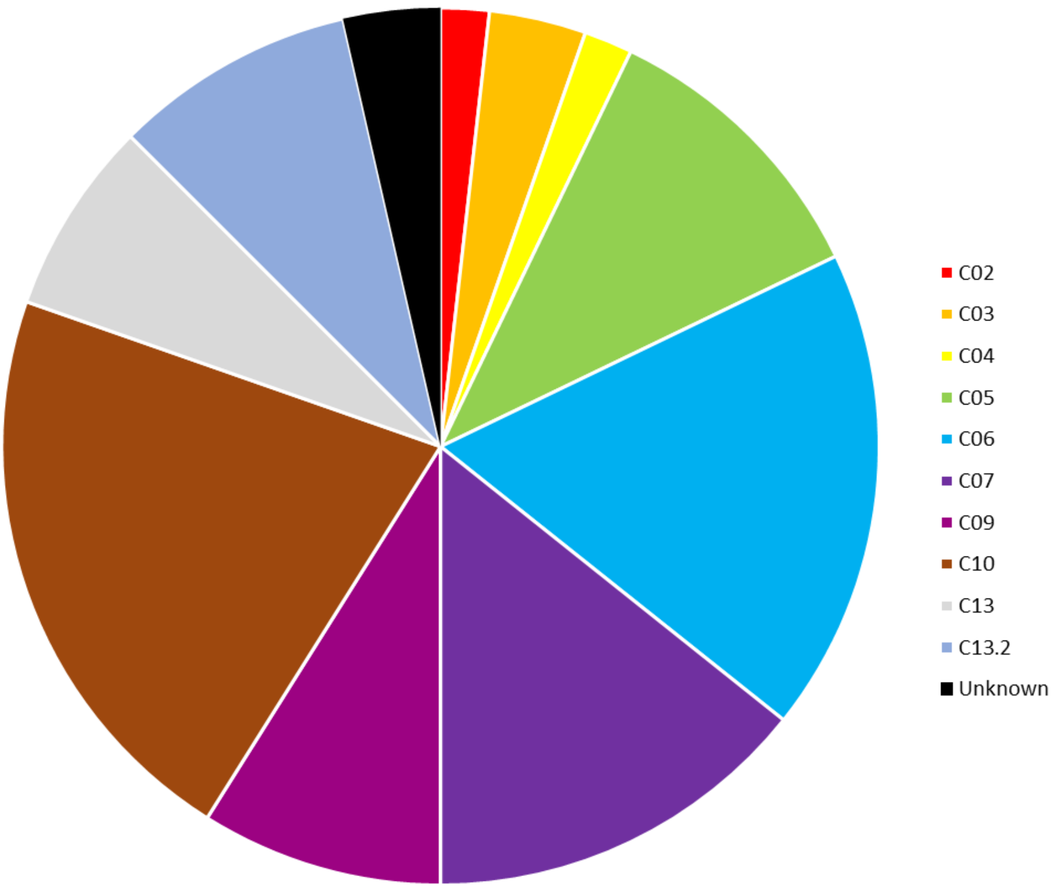


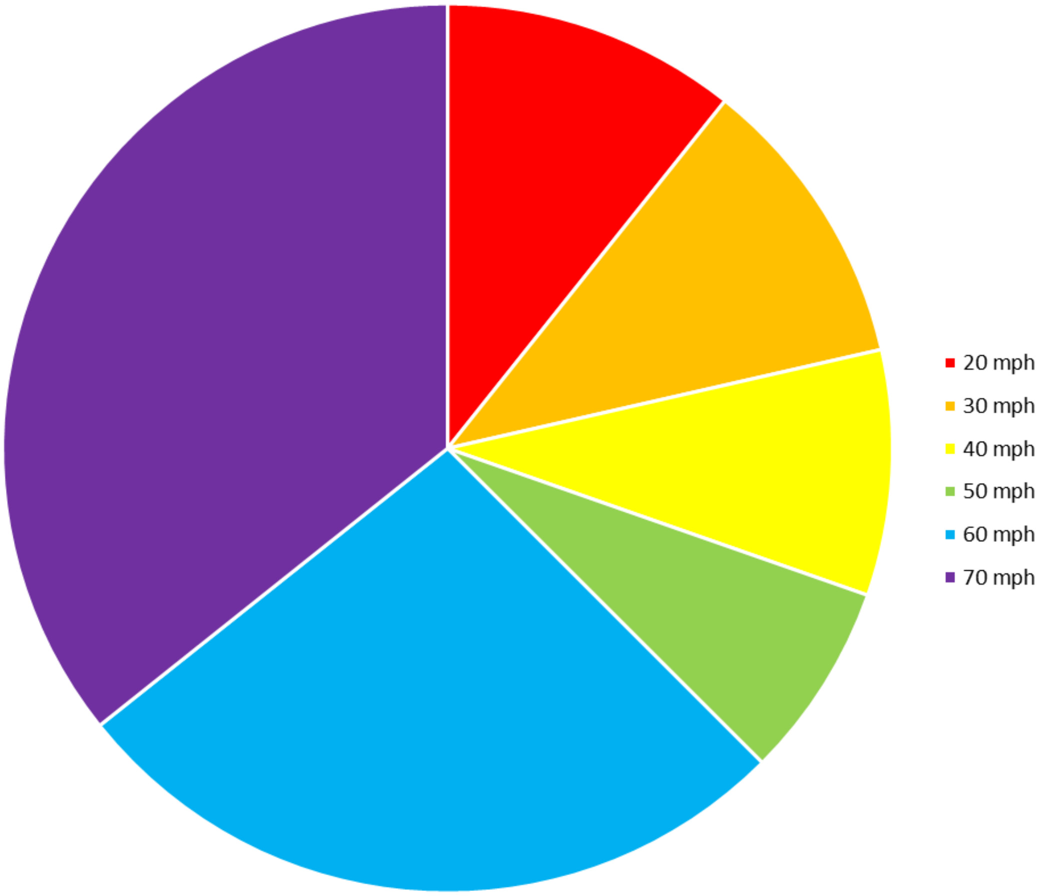
Table 4 shows the total number of sites for a given road speed limit.

Table 4: Number of sites surveyed in terms of the speed limit of the road

Speed (mph)	Number of Sites
20	6
30	6
40	5
50	4
60	15
70	20

Figure 4 shows the breakdown of survey sites by the speed limit of the road.

Figure 4: Breakdown of sites by speed limit



3. Survey results

A summary of the number of measured vehicles in each category and the range of vehicle speeds captured, at each survey site, is given in Table 5. The *L*, H_1 an H_2 terminology for the vehicle classes comes from the SPB procedure (see Appendix A) and aligns with the vehicle categories 1-3 in the IMAGINE methodology (see Table 7). Where appropriate (i.e. for medium or high-speed roads as defined in the SPB methodology) an indication of the acoustic performance of the road surface is provided in the final column. Whilst this metric is derived using the equations for RSI (see Appendix A), it is termed RSC (for Road Surface Correction) in acknowledgement of the fact that the sites did not necessarily comply with all the requirements of an SPB measurement stipulated in the SPB methodology (REF 12). As such these values should only be considered indicative of the acoustic performance of the road surface.

At low-speed sites an RSC value is not provided for two reasons:

- Firstly, the presence of soft ground between the microphone and the road at many of the sites leads to lower noise levels than would be expected from sites with intervening hard ground. This can be seen in the graphs of the results presented in Appendix C and is discussed further in Section 4.1.
- Secondly, the contribution of propulsion noise at low speed flattens the speed dependency of the vehicle noise level, such that when the data is extrapolated to the high-speed reference points for the calculation of an RSI unrealistically low levels are predicted.

Overall, the full speed range of the methodology (20 km/h to 130 km/h) was covered and there was an 11 dB range between the acoustic performance of the quietest and loudest road surface.

Table 5: Number of vehicles measured, speed range and surface performance

Site ID	Number of vehicles measured*			Speed range (km/h)	RSC dB(A)
	L	H_1	H_2		
A-20-N1	79	19	9	25 to 65	N/A
A-30-N2	86	3	5	24 to 59	N/A
A-40-N3	51	3	19	42 to 84	N/A
B-30-N1	50	3	10	24 to 54	N/A
B-20-N2	95	0	0	21 to 65	N/A
B-20-N3	75	3	0	27 to 72	N/A
C-30-N1	85	0	1	35 to 62	N/A
C-40-N2	146	0	1	31 to 74	N/A
D-30-N1	90	3	19	34 to 87	N/A
D-20-N2	101	0	0	28 to 71	N/A
D-20-N3	96	5	0	30 to 70	N/A
E-20-N1	71	0	0	28 to 82	N/A
E-30-N2	93	6	2	35 to 72	N/A
E-30-N3	104	2	0	24 to 60	N/A
F-40-N1	94	3	6	45 to 91	N/A
F-40-N2	65	1	1	44 to 83	N/A
F-40-N3	94	0	1	30 to 81	N/A
G-70-N1	130	12	5	68 to 108	-1.2

Site ID	Number of vehicles measured*			Speed range (km/h)	RSC dB(A)
	L	H_1	H_2		
G-60-N2	127	19	4	30 to 87	N/A
H-70-N1	119	8	11	60 to 123	0.9
H-70-N2	126	8	13	64 to 115	0.1
I-70-N1	87	42	21	63 to 115	N/A
I-70-N2	104	12	31	85 to 142	-3.3
I-70-N3	73	10	23	64 to 132	-5.4
J-50-N1	124	10	13	37 to 103	N/A
J-50-N2	85	6	15	61 to 90	N/A
J-70-N3	128	8	9	52 to 94	N/A
K-60-N1	31	0	3	79 to 126	N/A
K-70-N2	98	8	22	62 to 117	1.1
K-70-N3	126	23	5	65 to 128	-1.6
L-70-N1	141	6	10	74 to 128	-7.6
L-70-N2	119	12	25	85 to 148	-1.5
L-70-N3	154	3	7	63 to 123	0.8
M-70-N1	116	7	32	71 to 126	-1.5
M-70-N2	96	8	24	78 to 139	-1.6
M-70-N3	77	9	64	43 to 132	0.6
N-70-N1	87	7	34	66 to 111	1.7
N-70-N2	100	18	36	76 to 115	N/A
O-60-N1	122	8	22	67 to 116	-2.4
O-60-N2	123	9	19	63 to 95	3.5
O-60-N3	115	11	26	60 to 97	1.8
P-70-N1	127	11	4	79 to 125	-3.4
P-60-N2	76	6	4	58 to 113	-1.1
Q-70-N1	51	7	43	67 to 116	N/A
Q-70-N2	51	2	19	80 to 133	-0.5
R-60-N1	93	8	49	51 to 110	2.4
S-70-N1	265	12	30	70 to 130	-5.1
T-60-N1	106	43	55	53 to 100	-1.3
T-60-N2	97	18	51	38 to 105	-3.2
U-60-N1	108	32	55	57 to 113	-2.4
U-60-N2	86	19	47	65 to 121	-2.4
V-50-N1	193	19	26	57 to 96	-0.1
V-50-N2	36	8	12	50 to 88	N/A
W-60-N1	148	47	49	60 to 100	-6.4

Site ID	Number of vehicles measured*			Speed range (km/h)	RSC dB(A)
	L	H_1	H_2		
W-60-N2	72	15	22	67 to 99	-6.1
X-60-N1	177	48	66	49 to 95	1.4
Total	5769	610	1080	21 to 148	-7.6 to +3.5

* L, H_1 and H_2 are the totals of all vehicle sub-categories in Table 1 starting L, H1 and H2 respectively

Figure 5 shows the RSC values listed in Table 5 plotted by surface type against surface age. There is quite a bit a variability in the data, as may be expected from surveys not strictly adhering to the SPB requirements, but overall the results support the conclusions of previous work (REF 15) in terms of a reduction in the acoustic performance with age. Considered in conjunction with the full set of results presented in Appendix C and previous studies on the topic (REF 15), the broad set of road surface performances, upon which the analysis of road surface corrections for the revised method is based, is given in Table 6.

Table 6: Road surface performance with age

Road surface	RSC at 1 year dB	Degradation rate (dB/yr)
Hot rolled asphalt	-0.5	0.2
TSCS 6 mm	-6	0.5
TSCS 10 mm	-6	0.5
TSCS 14 mm	-4	0.5
Surface dressing	+0.5	-
Brushed concrete	+1	0
LDG concrete	-3	-

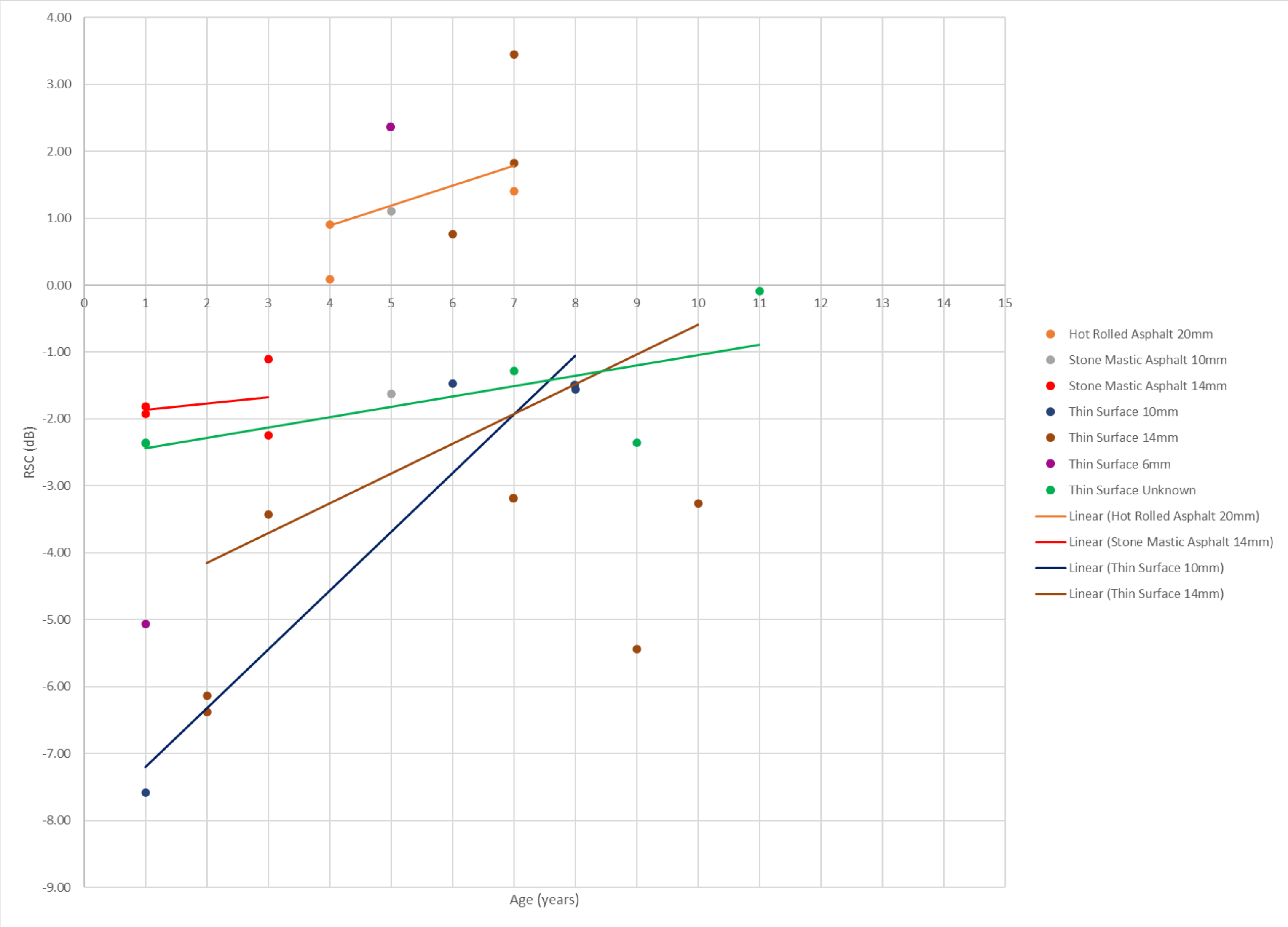
With respect to the data in Table 6, the following explanatory notes are made:

- The RSC for hot rolled asphalt is given with respect to 20 mm aggregate size. Hot rolled asphalt with a smaller aggregate size, such as the hot rolled asphalt 14 mm identified with respect to some of the low-speed survey sites, may be quieter than this but limited data at high vehicle speeds exists to verify this assumption. As such, adopting a precautionary approach, it is suggested that it be assigned the same correction until such time as further evidence is collated.
- Theory suggests that it is possible for TSCS 6 mm to be quieter than TSCS 10 mm but data on TSCS 6 mm is currently somewhat limited and does not demonstrate a clear jump in acoustic performance from many of the quieter TSCS 10 mm surfaces. As such, it is attributed the same acoustic performance as that of a TSCS 10 mm at this time. This may be revisited in the future as TSCS 6 mm becomes more commonplace.
- Table 3 identifies some surfaces as Stone Mastic Asphalt (SMA). This information has been drawn from the same field in PAMS that also identifies TSCSs but does not, in itself, give any indication as to whether the SMA is part of a thin surface layer. However, through an examination of both the layer thickness field in the PAMS data and the typical noise levels for surfaces labelled as SMA, it is considered that it is appropriate to treat such surfaces as TSCSs for the purpose of noise classification. Therefore, a surface labelled as SMA would adopt the assumed performance of TSCS with the same aggregate size, as given in Table 6.
- LDG stands for longitudinal diamond grinding and is a treatment applied to concrete road surfaces that can make them much quieter, as evidenced in the 2012 Transport Research Laboratory report (REF 17). As part of this study no measurements of an LDG concrete surface were made, however, results from previous work have been used in inform the correction listed in Table 6. Since there have not been any studies on its acoustic performance with age, a

conservative estimation of its acoustic performance when new is proposed as no degradation rate is applied.

- There is relatively limited data on surface dressing, but several sites with surface dressing have been measured as part of different studies or product approval procedures and acoustic performance is typically similar regardless of surface age. Therefore, while a degradation rate is not listed, in acknowledgement of the limited data, there is a little less uncertainty here than with LDG concrete.
- The initial RSC for each road surface is given for a road surface that is one year old, to align with product testing where new road surfaces are assessed between 12 and 24 months (REF 13).
- While Table 6 gives a useful top-level overview of the relative acoustic performance of the different road surfaces, RSC values are not used in the revised method. Instead, the performance of the road surface is accounted for through 1/3rd octave band adjustments to the sound power levels of the vehicles; see Section 4.5 for further details.

Figure 5: Road surface performance with age



4. Analysis

4.1 Methodology

The purpose of the roadside noise surveys was to collect data that would support the adjustment of the IMAGINE methodology to suit the vehicle fleet and road surfaces in the UK. These adjustments are made to the speed dependent rolling and propulsion sound power levels of the vehicles themselves, in 1/3rd octave bands. The full structure of the method is presented in the draft standard report (REF 11) but it is useful to present the basic framework in this section in order to understand the description of the analysis that follows.

The IMAGINE methodology treats each individual vehicle as an equivalent moving point source with a sound power level split into rolling noise and propulsion noise components. The sound power associated with the rolling noise for each vehicle category is given by:

$$L_{WR} = A_R + B_R log_{10}\left(\frac{v}{v_{ref}}\right) \quad (1)$$

where A_R and B_R are constants in each 1/3rd octave band for each vehicle class, v is the speed of the vehicle in km/h and v_{ref} = 70 km/h. The sound power associated with the propulsion noise for each vehicle category is given by:

$$L_{WP} = A_P + B_P\left(\frac{v - v_{ref}}{v_{ref}}\right) \quad (2)$$

where A_P and B_P are constants in each 1/3rd octave band for each vehicle class. These equations describe the sound power levels of a vehicle class over the speed range 20 km/h to 130 km/h with respect to a series of reference conditions. When local conditions vary from these reference conditions, corrections to these levels are applied, many of which have their own associated coefficients. As such, the constants A_R, B_R, A_P and B_P are what are referred to below as the 'core coefficients' and any other parameters that are altered as part of the validation process are termed 'correction coefficients'.

This analysis was conducted using a bespoke software tool based on the open-source point-to-point implementation of the Harmonoise method, produced under the 2014 project to develop and implement harmonised methods (REF 18). A brief description of this software is given in Section 4.2. The analysis procedure for this validation exercise is broken down as described in the following paragraphs.

Define a suitable distance at which comparisons between measured and calculated sound pressure levels should be made. Due to the constraints of local site conditions, vehicle noise levels were measured at different distances from the road edge from site to site. For this study, the distance specified in the SPB methodology (REF 12) was used for comparison purposes. As such, all measured sound pressure levels were first corrected, under the assumption of point source propagation, to a point 7.5 m from the centre of the trafficked lane. The IMAGINE methodology considers the sources of vehicle noise to be located in the plane of the nearside wheel track (REF 8) and therefore this distance was used in the calculation software when calculating receiver levels. Note that this would result in a different source position for receivers on the other side of the road.

Determine the vehicle categories to be used in the revised methodology. The IMAGINE methodology categorises vehicles into certain classes and sound power levels are described in terms of a typical vehicle belonging to that class. As part of this work, all the vehicle sub-classes given in Table 1 were considered, including whether or not they warranted separate categorisation for the purpose of defining sound power levels. The results of this analysis are described in Section 4.3.

Determine the reference surface to be used in the revised methodology. The IMAGINE methodology uses a reference surface (i.e. one for which no further corrections to the sound power level are required) described as a mixture of Stone Mastic Asphalt and Dense Asphalt Concrete with an 11 mm chip size, mid-way through its service life. However, the reference surface used in the existing national methodology in the UK (i.e. CRTN) is a virtual surface with an RSI of 0[1]. For continuity purposes it is preferred to continue to use the CRTN reference surface in the revised methodology. The process for determining core rolling and propulsion sound power coefficients for this reference surface is described in Section 4.4.

Consider local site conditions in selecting appropriate vehicles. Both the SPB method and the analysis software (see Section 4.2) work on the assumption of acoustically hard ground between the microphone and the road. At some survey sites, particularly those adjacent to low-speed roads, soft verges exist between the road and the microphone, and this can result in a greater level of sound absorption and scattering, and therefore lower measured levels. The impact of this is evident in some of the data presented in Appendix C where sound pressure levels measured at low-speed are lower than would be expected, given equivalent high-speed sound pressure levels and the known relationship between vehicle noise and speed. Data from these sites is still informative and will be very useful in helping to validate elements of the propagation method, such as ground absorption and scattering models, but these results have not been used to determine RSC values.

Determine the corrections to the sound power levels required to account for common road surface types found in the UK. Survey data, as presented in Appendix C, is collated according to road surface type and this has, along with historical data (REF 15), been used to determine 1/3rd octave band corrections for each of the classes of road surface. Consideration has also been given to the age of the road surface and the speed dependency of the measured sound pressure levels. Further details on this process and the resulting decisions made with respect to road surface corrections are given in Section 4.5.

Consider the range of other factors that may influence the vehicle sound power levels including the impact of air and surface temperature. There are a range of additional variables that can influence the source noise of motor vehicles and, whilst these factors could not be explicitly validated through the survey programme, their impact and how they may be modelled has been considered as part of this work. The result of this desk-based exercise is presented in Section 4.6 and the potential work involved in further validating these parameters is summarised in Section 5.

4.2 Software

Analysis was conducted through the use of software based on both the revised source methodology and a limited, short-range, point-to-point implementation of the Harmonoise method. The raw C++ code has been translated to C# and packaged as an executable with an added graphical user interface (GUI).

Figure 6 shows the interface, with (rolling, propulsion and total) sound power levels displayed on the graph on the left and sound pressure levels at the receiver position on the right. The blue curve on the right represents the calculated sound pressure level using the revised methodology over the range of 1/3rd octave frequency bands while the red curve on the same graph represents the equivalent measured result, calibrated to 7.5 m from the lane centre. In adjusting the coefficients in the model, the aim is for the blue curve to represent an average of the measured data for vehicles in the associated class.

While the GUI allows for the adjustment of additional parameters such as vehicle speed, path length and surface wetness, these settings were only used to gain a broad understanding of their relative impact. Adjusting them did not form part of the core validation exercise as for this they are fixed to the values associated with the corresponding measurement.

[1] This is often considered to be equivalent to a newly laid Hot Rolled Asphalt surface with a 20 mm chip size but is not defined as such.

Figure 6: Layout of the analysis software

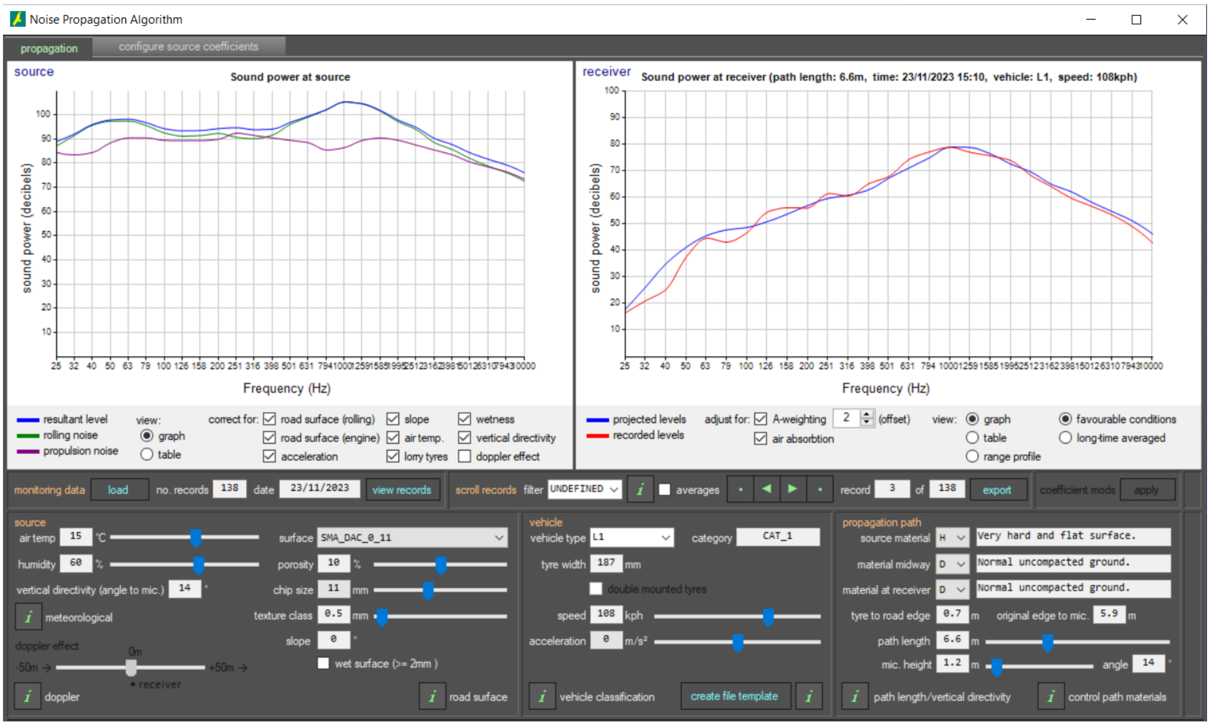


Figure 7 shows the part of the software where the coefficients inherent in the equations described in (REF 11), including equations (**1**) and (**2**) above, can be adjusted in order to immediately visualise the impact this has on overall levels through the interface shown in Figure 6.

Figure 7: Adjustable coefficient tables in the software

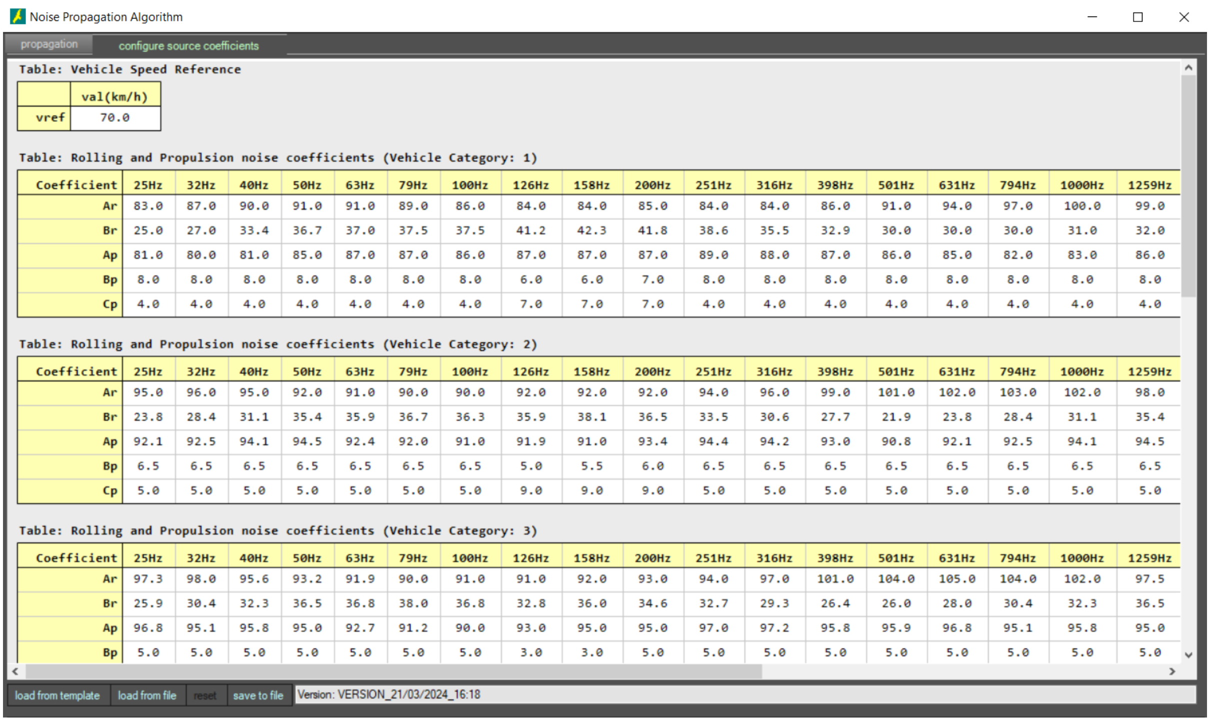


Table: Vehicle Speed Reference

	val(km/h)
vref	70.0

Table: Rolling and Propulsion noise coefficients (Vehicle Category: 1)

Coefficient	25Hz	32Hz	40Hz	50Hz	63Hz	79Hz	100Hz	126Hz	158Hz	200Hz	251Hz	316Hz	398Hz	501Hz	631Hz	794Hz	1000Hz	1259Hz
Ar	83.0	87.0	90.0	91.0	91.0	89.0	86.0	84.0	84.0	85.0	84.0	84.0	86.0	91.0	94.0	97.0	100.0	99.0
Br	25.0	27.0	33.4	36.7	37.0	37.5	37.5	41.2	42.3	41.8	38.6	35.5	32.9	30.0	30.0	30.0	31.0	32.0
Ap	81.0	80.0	81.0	85.0	87.0	87.0	86.0	87.0	87.0	87.0	89.0	88.0	87.0	86.0	85.0	82.0	83.0	86.0
Bp	8.0	8.0	8.0	8.0	8.0	8.0	8.0	6.0	6.0	7.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Cp	4.0	4.0	4.0	4.0	4.0	4.0	4.0	7.0	7.0	7.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

Table: Rolling and Propulsion noise coefficients (Vehicle Category: 2)

Coefficient	25Hz	32Hz	40Hz	50Hz	63Hz	79Hz	100Hz	126Hz	158Hz	200Hz	251Hz	316Hz	398Hz	501Hz	631Hz	794Hz	1000Hz	1259Hz
Ar	95.0	96.0	95.0	92.0	91.0	90.0	90.0	92.0	92.0	92.0	94.0	96.0	99.0	101.0	102.0	103.0	102.0	98.0
Br	23.8	28.4	31.1	35.4	35.9	36.7	36.3	35.9	38.1	36.5	33.5	30.6	27.7	21.9	23.8	28.4	31.1	35.4
Ap	92.1	92.5	94.1	94.5	92.4	92.0	91.0	91.9	91.0	93.4	94.4	94.2	93.0	90.8	92.1	92.5	94.1	94.5
Bp	6.5	6.5	6.5	6.5	6.5	6.5	6.5	5.0	5.5	6.0	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Cp	5.0	5.0	5.0	5.0	5.0	5.0	5.0	9.0	9.0	9.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Table: Rolling and Propulsion noise coefficients (Vehicle Category: 3)

Coefficient	25Hz	32Hz	40Hz	50Hz	63Hz	79Hz	100Hz	126Hz	158Hz	200Hz	251Hz	316Hz	398Hz	501Hz	631Hz	794Hz	1000Hz	1259Hz
Ar	97.3	98.0	95.6	93.2	91.9	90.0	91.0	91.0	92.0	93.0	94.0	97.0	101.0	104.0	105.0	104.0	102.0	97.5
Br	25.9	30.4	32.3	36.5	36.8	38.0	36.8	32.8	36.0	34.6	32.7	29.3	26.4	26.0	28.0	30.4	32.3	36.5
Ap	96.8	95.1	95.8	95.0	92.7	91.2	90.0	93.0	95.0	95.0	97.0	97.2	95.8	95.9	96.8	95.1	95.8	95.0
Bp	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

There is potential for the software to be updated to include rail source terms, and additional propagation elements, as the other parts of the revised method develop further.

4.3 Vehicle categories

The IMAGINE methodology splits vehicles into categories described as light motor vehicles, medium heavy vehicles, heavy vehicles, and powered two-wheelers. As part of this work, surveyed vehicles were categorised into a wider variety of classes as described in Table 1. By looking for trends in the noise levels of these various sub-classes of vehicle, it could be determined whether or not it would be worthwhile to determine separate core coefficients for these sub-classes. In conclusion, it was found that:

- Vans under 3.5 tons were, on average, slightly (around 0.5 dB) louder than cars at low speed. This implies that they typically exhibit slightly more engine noise than cars, but that their rolling noise is approximately the same. In the IMAGINE method the percentage of vans making up category 1 is stated but there is only one set of core coefficients for vehicles in category 1. However, in the revised method, they form their own sub-class of category 1 vehicles with their own propulsion noise components which are 1 dB higher than those for cars in the 160 Hz to 500 Hz bands. In practice, data on the percentage of vans in the traffic stream may not be known but this could always make use of national statistics by way of an approximation.
- Electric cars were slightly quieter than their internal combustion engine equivalents at low speed, supporting previous studies which have confirmed their quieter propulsion noise component. Not enough electric vehicles were identified in the study to draw definitive conclusions as to the exact values of the coefficients to be used, so results from a previous study, the FOREVER project (REF 19), were used to inform appropriate coefficients. The aim of the FOREVER work was to determine correction coefficients for electric cars for the CNOSSOS-EU calculation method (REF 5) which was itself derived from the IMAGINE structure. Therefore, results from this study, given in octave band corrections with respect to the original default set of coefficients, were interpolated in order to provide sound power propulsion noise coefficients for electric cars in the revised method. As with vans, national statistics on the percentage of electric vehicles may be used to incorporate these revised sound power levels in practice, although assumptions would need to be made with respect to the propulsion mode of hybrid vehicles.
- No noticeable trends with respect to the other vehicle sub-classes identified in Table 1 were identified that would warrant further sub-division of any of the vehicle categories.

The final set of vehicle categories for the revised method is given in Table 7, along with the corresponding UN ECE vehicle classification for each category. The only change from the IMAGINE method being the division of category 1 vehicle into three separate sub-classes. Tables of all the adjusted coefficients to be used in the revised method are provided in Appendix D and all coefficients forming part of the method are given in the draft standard (REF 11).

Table 7: Vehicle categories in the revised method

Category	Name	Description	UNECE Vehicle Class[2]
1	Light motor vehicles	1C – Passenger cars < 3.5 tons	M1
		1V – Delivery vans < 3.5 tons	N1
		1CE – Passenger cars < 3.5 tons when powered by an electric motor	M1
2	Medium heavy vehicles	Delivery vans, trucks and buses > 3.5 tons, with two axles	M2, M3 and N2, N3
3	Heavy vehicles	Heavy duty vehicle > 3.5 tons with more than two axles	M2 and N2 with trailer, M3 and N3
4	Powered two wheelers	4A – mopeds and quads up to 50cc	L1, L2, L6
		4B – motorbikes over 50cc	L3, L4, L5, L7

[2] As defined in ECE/TRANS/WP.29/78/Rev.7

4.4 Core coefficients

The graphs in Appendix C each show a black line passing through a set of noise levels that can be considered representative of those corresponding to vehicles (in the given category) on a reference surface with an RSI of 0. This line was derived as follows:

- A prior study into determining RSI values without the full complement of heavy vehicles (REF 20) found relationships between the noise level of light vehicles and heavy vehicles, for a given road surface, that could be used to approximate the RSI quite accurately. These relationships were used to determine a typical ratio between noise levels of light vehicles, twin-axle heavy vehicles and multi-axle heavy vehicles.
- Noise levels were adjusted for light vehicles at 80 km/h to give a medium-speed RSI of 0, and at 110 km/h to give a high-speed RSI of 0 (the equations for these are given in Appendix A).
- Given the known logarithmic relationship between rolling noise and speed, see for example equation (**1**) above, a curve of the form *sound pressure level* = $X*log_{10}(speed)+Y$ was created that passed through these points. This curve gives an indication of the noise levels to be expected on a road surface of RSI=0 in other speed ranges.

From an analysis of the 1/3rd octave data for vehicles that sit close to this line[3], at high speed, core (A_R) coefficients for the rolling noise component were derived. The Hot Rolled Asphalt (HRA) surfaces were chosen for this analysis. The high-speed data for HRA typically indicated good agreement with the speed dependency of the RSI=0 curve, so only small adjustments were made to the default coefficients B_R from the IMAGINE model.

With the rolling noise coefficients fixed, the low-speed data was analysed to determine appropriate propulsion noise coefficients. Adjustments were made primarily to the A_P coefficients, with limited evidence to suggest that the propulsion noise variation with speed, determined by B_P, needed much adjustment.

4.5 Remaining surfaces

With the core coefficients in place, correction terms for each of the road surface types could be determined. For each road surface category given in Table 6, vehicles that are close to the corresponding expected performance of the road surface, given by the RSC in Table 6, were analysed to determine appropriate correction factors. The initial analysis focussed on high-speed data where rolling noise dominates and concentrated primarily on relatively new road surfaces. Analysis of the older road surfaces did not suggest any significant spectral variation and therefore the age dependent corrections given in Table 6 are proposed as flat corrections to the 1/3rd octave data, which by default relates to a surface that is one year old. Similarly, if the RSI of the road surface to be modelled is known then it is suggested that a broadband correction to the coefficients relating to that surface type may be applied.

The speed dependency of the vehicle noise levels on each surface was also analysed to determine the corresponding correction coefficient. Results supported the conclusion from the IMAGINE work (REF 8) that, for low noise surfaces (including TSCS), this coefficient is negative. In other words, there is less variation with speed in the rolling noise on a TSCS than on the reference surface. However, for brushed concrete and Hot Rolled Asphalt speed dependency was found to follow that of the reference surface more closely.

Correction coefficients for the road surface types given in Table 6 are presented in Appendix D.

4.6 Other factors

In addition to the vehicle category and road surface, there are a number of other factors that can influence the sound power levels of the vehicles. The approach to examining these parameters is presented in Appendix B of the report on Task 2 of this work (REF 10). This section provides a brief summary on the evidence and approach to each of these factors, together with initial

[3] It should be noted that the measured 1/3rd octave data reflects the instantaneous, A-weighted and fast-weighted, sound pressure, L_p, at the start of the 100 ms sampling window, as opposed to the L_{AFmax} which is the maximum value within the 100 ms window. Nevertheless, analysis of the data showed that this discrepancy was very small (around 0.1-0.2 dB) in most instances.

recommendations with respect to their inclusion in the revised method. Section 5 summaries, at a top-level, the work that would be required to further validate these components of the methodology.

Air temperature. Rolling noise is corrected for air temperature in the IMAGINE model and varies according to surface type. While air and road surface temperature measurements were taken as part of the survey work it is difficult to use this information to further validate the correction terms since the air temperature did not vary much on any given survey and the impact of the air temperature cannot be disaggregated from the effect of the road surface for data across multiple survey sites. The corrections in the IMAGINE model (REF 8) were compared to those given in HAPAS documentation (REF 13) and similar results were found. Both methods indicate that vehicle noise levels decrease by around 0.05 dB/°C. In other words, calculated levels need to be adjusted upwards when the temperature is high, and downwards when the temperature is low. It is recommended that the revised method adopt the IMAGINE correction terms until such time as more validation data are available.

Vehicle engine type. This is discussed in Section 4.3 for vans under 3.5 tons and electric cars. It is recommended that the initial revised method exclude further corrections (present in the IMAGINE model) with respect to diesel cars and illegal replacement silencer systems (IRESS). The percentage of diesel cars on UK roads continues to fall[4] and this study was not able to validate the correction in the IMAGINE model which itself reflects diesel vehicles on the road in the early 2000s. Additionally, small corrections to the propulsion noise for diesel cars would not lead to noticeable changes in the overall calculated sound levels for light vehicles. Similarly, it is not recommended that the initial version of the revised method consider illegal replacement silencer systems (IRESS) as there is a high degree of uncertainty with respect to both their noise emissions and prevalence on any given road. It is possible that the method could be updated in the future to include such corrections, perhaps supported by the ongoing work on roadside noise cameras (REF 21, REF 22). It should be noted however that the coefficients for vehicle category 4 (powered two wheelers) inherently assumes a ratio of 35% IRESS. It is outside the scope of this work to consider further validation of category 4 vehicles. Potential work to update these terms is included in Table 8 in Section 5.

Acceleration and deceleration. Correction terms for vehicles under acceleration or deceleration are incorporated in the IMAGINE model in terms of variations in the propulsion noise. These terms are based on relatively limited studies and were not validated as part of this work. Nevertheless, they are incorporated into the initial revised method to allow for the potential impact of acceleration close to junctions, which can lead to noise complaints. Although the FOREVER project found that electric vehicles can be slightly louder when accelerating and braking (REF 23), no corrections for the acceleration of electric vehicles were proposed since (i) the sample set was quite small, (ii) differences varied depending upon the rate of acceleration, with some results for slow deceleration yielding quieter levels, and (iii) a literature review found that other work concluded that "…the noise emission from the electric vehicle was similar at constant speed and under acceleration, contrary to conventional vehicles for which acceleration increases noise." As such, no corrections for the acceleration or deceleration of electric vehicles are proposed for the revised method until research on the topic is more conclusive.

Road gradient. Both the IMAGINE model and CRTN include a correction for the gradient of the road, and it is proposed to use the existing IMAGINE model correction terms in the revised method. The extent to which the road gradient correction applies to electric cars is not fully understood but is retained, as a precautionary measure, for the time being. As the road gradient correction applies to the propulsion noise component which, for electric cars, is already very low it is unlikely to have a noticeable impact on overall calculated sound pressure levels.

Surface wetness. The IMAGINE model includes a correction to the rolling noise component of light vehicles for 2 mm of water layer thickness on the road. This correction increases the rolling noise at high frequencies (above 1 kHz). One survey conducted as part of this study was completed with a damp road surface. While noise levels were slightly higher than expected for the surface type and age, supporting the conclusion that levels are higher in the wet, it is difficult to disaggregate the effect of the wetness from how the surface would have performed in the dry. The IMAGINE correction is retained in the revised method so that it is possible to consider the impact of surface wetness if required, although it may be that in practice it is seldom used.

[4] https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables

Truck axles and tyre widths. Variations to these parameters, for category 3 and category 1 vehicles respectively, are accounted for in the IMAGINE model. It is proposed to keep these correction terms in the revised method to allow for sensitivity testing if required, although the default values are likely to be used in practice most of the time.

Directivity of point sources. As explained in the Task 2 report, it is proposed to include these terms from the IMAGINE framework in the revised method. There has been no fundamental change to the sources of vehicle noise in the intervening period that would suggest these terms are not fit for purpose. Correction terms exist for both vertical and horizontal directivity with only the vertical directivity being of relevance for calculations concerning noise exposure, as in these instances the horizontal directivity is lost in the aggregation of the vehicles as equivalent point sources into a line source of traffic. However, for calculations of L_{Amax} the horizontal directivity does need to be factored into the propagation of the sound. One thing guidance documents accompanying the method would need to consider concerns the assumptions to be made when calculating L_{Amax}, as vehicle sound power levels are derived on the basis of average values for each class. It is assumed that some form of upper percentile on the full spread of vehicle data could be adopted for this purpose.

Added sound. Vehicles operating in electric mode are required to achieve minimum sound levels in accordance with UN ECE Regulation 138 (REF 24). This is achieved through the use of an Acoustic Vehicle Alerting System (AVAS) which generates an artificial sound to act as an audible warning for Vulnerable Road Users (VRUs), in particular people with impaired vision. The sound from such systems is not modelled within the IMAGINE method, and has not been measured as part of this work. An AVAS is only required to operate up to 20 km/h, which is the lower bound of the validity of both CRTN and the revised method. Therefore, while it is permissible for some AVAS to operate above 20 km/h, it is not considered a high priority for inclusion in the calculation method. However, given the approach used in CNOSSOS-EU[5] of setting vehicle speeds to 20 km/h in cases where speeds are less than 20 km/h, it could be considered for inclusion in these situations. Further research into this element is listed as a potential future enhancement in Section 5.

4.7 Aggregation to traffic flow

To calculate the noise exposure from traffic on a given road, the single vehicle sound power levels need to be translated to an equivalent sound pressure level at a receiver position, averaged over a certain time period. A description on how this can be achieved is provided in the Harmonoise report (REF 8) and may be summarised as follows:

- For each vehicle class, calculate an equivalent line source strength (average sound power per unit length) for the rolling and propulsion noise contributions separately at their given source height. The line source is calculated from the vehicle class sound power level, the total flow of vehicles in that class and the average speed of those vehicles.
- The sound emission of the vehicles on the road is then represented by a series of evenly distributed, incoherent point sources with a total sound power made up of the equivalent line source strength and the length of the section represented by the point source in metres.
- The equivalent sound power levels for different groups of vehicles (e.g. by vehicle class or speed) or different lanes can then be summed from the separate equivalent line sound power levels.

[5] While not explicitly stated in the CRTN memorandum, this is also the approach taken by many practitioners when performing calculations using CRTN.

5. Future Enhancements

This study has focussed on the validation of the key parameters that have a noticeable impact on the sound emissions of vehicles in the majority of commonly encountered scenarios contributing to road traffic noise exposure. However, as indicated in Section 4.3, there are numerous other factors which can have an influence on the sound emissions in certain circumstances. The IMAGINE method provides an indication as to how these factors could be included within the calculation of sound power levels. However, some of these approaches are based on relatively small studies and have not been further validated since the IMAGINE work completed around 2007. Therefore, further research into these factors would be beneficial. In addition, some extra vehicle classes not currently included in the IMAGINE method, such as vehicles with AVAS and electric trucks or buses, could also be added in the future. Table 8 provides an overview of the amount and type of work that would likely be required to fully address these topics. While it is not considered necessary to complete such work prior to an initial release of the revised method, these studies act as touchstones for additional development of the methodology in the future.

The estimated time and budget required for such studies is categorised as follows:

- Small - up to 40 working days (about 2 months or less)
- Medium - up to 250 working days (about 1 year)
- Large - up to 500 working days (about 2 years)

Table 8: Potential future enhancements to the method

No.	Topic	Work required	Estimated time and budget
1	Acceleration and deceleration	Controlled vehicle measurements for different powertrain options, with measured acceleration rates and gear ratios	Medium
2	Road gradient	Controlled vehicle measurements on different gradients for fixed speeds and road surfaces	Medium
3	Surface wetness	Controlled vehicle measurements in varying weather conditions for fixed speeds and road surfaces	Medium
4	Directivity	Roadside measurements taken simultaneously at a fixed distance and varying horizontal and vertical angles	Small
5	Assumptions for L_{Amax}	An analysis of measure data under different conditions to determine appropriate corrections to the noise from a given vehicle calculated by the revised method as it stands	Small
6	Powered two-wheelers	Controlled measurements under a wide variety of vehicle operating conditions. A clear understanding of the number of modified exhaust systems	Large
7	Added sound	Controlled measurements at low speed, with and without an AVAS	Medium
8	Electric trucks and other future vehicle classes	Controlled measurements at low speed with a prescribed approach to separating the rolling and propulsion noise. An example approach for electric vehicles is given in (REF 25).	Medium

6. Summary

This report summarises work undertaken to validate the road vehicle sound powers used in the European IMAGINE model, developed in the early 2000s, with respect to the vehicle fleet and road surfaces in the UK in 2023/2024.

The validation exercise consisted of comparing results from a series of roadside vehicle noise measurements with results from a series of calculations using a short-range point-to-point implementation of the IMAGINE model. The intention is for the output of this work to form a core component of a revised national calculation methodology for road and rail noise.

A spreadsheet of calculations concerning vehicle sound power levels is provided separately for reference. Test cases concerning the calculation of sound pressure levels at receiver positions will be provided as part of the wider standard, incorporating the propagation element.

It is anticipated that alongside the new national calculation methodology, guidance documents concerning use of the standard will need to be updated or created as required depending on the application of the method. Such guidance would likely include a discussion on the uncertainty inherent in the model, see for example (REF 26), and appropriate traffic data requirements, see for example (REF 27 and REF 28).

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Appendix A SPB methodology

The SPB measurement methodology is the most frequently used procedure in the UK for assessing the influence of road surfaces on vehicle sound level emissions. It is a relatively simple procedure, and the results can be directly applied to the surfacing correction used during traffic noise calculations.

It is also the method used for noise classification within the Highways Authority Product Approval Scheme (HAPAS). The methodology is described in ISO 11819-1, however the reference speeds and RSI values are those defined in Appendix 8 of the HAPAS guidelines document for the assessment and certification of thin surfaces for highways.

During an SPB measurement, the maximum pass-by noise levels and speeds of individual vehicles selected from the traffic stream are measured at a reference distance of 7.5 m from the centre of the vehicle lane. The traffic population is classified as follows:

- *L* – light vehicles, including passenger cars and car derived vans, excluding vehicles towing trailers or caravans.
- *H1* – commercial trucks with 2 axles and greater than 3.5 tonnes unladen weight.
- *H2* – commercial trucks with more than 2 axles and greater than 3.5 tonnes unladen weight.

To provide statistically robust results a sample size of at least 100 *L* vehicles and at least 80 trucks with a minimum of 30 *H1* and 30 *H2* vehicles is required. For each vehicle category, a linear regression equation is derived between the maximum pass-by sound pressure level, L_{Amax}, and the logarithm of the vehicle speed (km/h). For each vehicle category, the estimated noise level, $L_{Amax,v}$, for a given reference speed, v km/h, is derived from the regression equation.

For a road speed category, the RSI value provides an estimate of the difference in traffic noise levels for typical traffic conditions on the tested surface with that from similar traffic on a reference surface. A reference surface is one for which no surface correction is required in the Calculation of Road Traffic Nosie. For high-speed roads this corresponds to a bituminous surface with a texture depth of 2 mm and in practice is generally considered as having the same acoustic performance as a 20 mm Hot Rolled Asphalt (HRA) surface.

For reference noise levels $L_{veh,L}$, $L_{veh,H1}$ and $L_{veh,H2}$ at 80 km/h, 70 km/h and 70 km/h respectively a medium speed RSI value is given by:

$$RSI_M = 10\log_{10}(11.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.629 \times 10^{\frac{L_{veh,H1}}{10}} + 0.157\ \times 10^{\frac{L_{veh,H2}}{10}}) - 92.3$$

For reference noise levels $L_{veh,L}$, $L_{veh,H1}$ and $L_{veh,H2}$ at 110 km/h, 90 km/h and 90 km/h respectively a high speed RSI value is given by:

$$RSI_H = 10\log_{10}(7.8 \times 10^{\frac{L_{veh,L}}{10}} + 0.578 \times 10^{\frac{L_{veh,H1}}{10}} + 10^{\frac{L_{veh,H2}}{10}}) - 95.9$$

Appendix B Site survey details

Table 9: Site survey locations, speed limits and road surfaces

Site Number	Site ID	Longitude	Latitude	Road Speed Limit (mph)	Surface	Surface Age (years)
1	A-20-N1	-0.162387395	51.397712621	20	Stone mastic asphalt 14mm*	2-5*
2	A-30-N2	-0.086543321	51.370784141	30	Stone mastic asphalt 14mm*	> 5*
3	A-40-N3	-0.115114807	51.351616522	40	Hot rolled asphalt 14mm*	> 5*
4	B-30-N1	-0.068110397	51.362708382	30	Stone mastic asphalt 10mm*	1-2*
5	B-20-N2	-0.032342557	51.363290231	20	Unknown	-
6	B-20-N3	-0.066116677	51.363635219	20	Hot rolled asphalt 14mm*	>5*
7	C-30-N1	-0.169681329	51.342460041	30	Stone mastic asphalt 14mm*	2-5*
8	C-40-N2	-0.152090682	51.342321091	40	Stone mastic asphalt 14mm*	>5*
9	D-30-N1	-0.146238493	51.619461960	30	Stone mastic asphalt 14mm*	>5*
10	D-20-N2	-0.194369948	51.643404270	20	Hot rolled asphalt 14mm*	>5*
11	D-20-N3	-0.108094081	51.651399378	20	Stone mastic asphalt 14mm*	1-2*
12	E-20-N1	-0.199298684	51.646344843	20	Unknown	-
13	E-30-N2	-0.279606849	51.664831992	30	Stone mastic asphalt 14mm*	1-2*
14	E-30-N3	-0.271257358	51.672135921	30	Hot rolled asphalt 14mm*	1-2*
15	F-40-N1	-0.311521728	51.673252485	40	Hot rolled asphalt 14mm*	>5*
16	F-40-N2	-0.289263101	51.702550109	40	Stone mastic asphalt 14mm*	2-5*
17	F-40-N3	-0.353958204	51.657276256	40	Stone mastic asphalt 10mm*	2-5*
18	G-70-N1	0.035000368	50.860696091	70	Thin surface unknown	15
19	G-60-N2	0.075287379	50.853881187	60	Thin surface unknown	11

Site Number	Site ID	Longitude	Latitude	Road Speed Limit (mph)	Surface	Surface Age (years)
20	H-70-N1	-0.430620165	50.839813307	70	Hot rolled asphalt 20mm	4
21	H-70-N2	-0.425782138	50.839969622	70	Hot rolled asphalt 20mm	4
22	I-70-N1	-0.063094283	50.865910945	70	Thin surface 14mm	9
23	I-70-N2	-0.055296594	50.866136651	70	Thin surface 14mm	10
24	I-70-N3	-0.044274998	50.865399225	70	Thin surface 14mm	9
25	J-50-N1	0.432824644	51.06846574	50	Stone mastic asphalt 14mm	1
26	J-50-N2	0.444593481	51.06067563	50	Stone mastic asphalt 14mm	1
27	J-70-N3	0.457090762	51.03707031	70	Stone mastic asphalt 14mm	3
28	K-60-N1	0.424303812	51.072588099	60	Unknown	2
29	K-70-N2	0.335690931	51.138478010	70	Stone mastic asphalt 10mm	5
30	K-70-N3	0.326496403	51.139255238	70	Stone mastic asphalt 10mm	5
31	L-70-N1	-0.691531098	51.988507540	70	Thin surface 10mm	1
32	L-70-N2	-0.510506533	51.921864484	70	Thin surface 10mm	6
33	L-70-N3	-0.548134000	51.913763000	70	Thin surface 14mm	6
34	M-70-N1	0.328400713	51.641514770	70	Thin surface 10mm	8
35	M-70-N2	0.305606142	51.634629844	70	Thin surface 10mm	8
36	M-70-N3	0.287945645	51.627927381	70	Thin surface 10mm	8
37	N-70-N1	0.521280373	51.73777239	70	Concrete (brushed)	42
38	N-70-N2	0.763970539	51.86816363	70	Surface Dressing	26
39	O-60-N1	-1.508079429	53.488351332	60	Thin surface unknown	9
40	O-60-N2	-1.541854624	53.485145169	60	Thin surface 14mm	7
41	O-60-N3	-1.587148933	53.485357176	60	Thin surface 14mm	7
42	P-70-N1	0.066698098	52.236100740	70	Stone mastic asphalt 14mm	3
43	P-60-N2	0.091177424	52.233282557	60	Thin surface 14mm	3

Site Number	Site ID	Longitude	Latitude	Road Speed Limit (mph)	Surface	Surface Age (years)
44	Q-70-N1	-0.046995146	52.288116093	70	Thin surface 10mm	8
45	Q-70-N2	0.522720191	52.329967784	70	Concrete (brushed)	33
46	R-60-N1	-1.760965555	53.498679404	60	Hot rolled asphalt 20mm	5
47	S-70-N1	-0.915450295	50.857020052	70	Thin surface 6mm	1
48	T-60-N1°	-1.627778	50.977021	60	Thin surface unknown	7
49	T-60-N2°	-1.629838	50.977886	60	Thin surface 14mm	7
50	U-60-N1°	-1.903877	51.166614	60	Thin surface unknown	1
51	U-60-N2°	-1.904708	51.166553	60	Thin surface unknown	1
52	V-50-N1°	-1.836986	51.079591	50	Thin surface unknown	11
53	V-50-N2°	-1.838786	51.079821	50	Thin surface unknown	11
54	W-60-N1°	-1.936704	51.134301	60	Thin surface 14mm	2
55	W-60-N2°	-1.935276	51.134179	60	Thin surface 14mm	2
56	X-60-N1°	-1.867776	51.097566	60	Hot rolled asphalt 20mm	7

*estimated from photographs of the road surface

°site survey completed in 2021 as part of the COVID-19 lockdown monitoring work

Table 10: Site weather conditions

Site ID	Date	Air temperature (˚C)	Surface temperature (˚C)	Wind speed Average (m/s)
A-20-N1	27th September 2023	20 -22	23 to 25	0.5 to 1.5
A-30-N2	27th September 2023	22 - 23	22	0.6 to 0.8
A-40-N3	27th September 2023	20	17 - 18	<0.5
B-30-N1	28th September 2023	18 to 23	18	0.8 to 1.6
B-20-N2	28th September 2023	22	16 to 18	0.5 to 1.2
B-20-N3	28th September 2023	18 to 19	18 to 19	0.9 to 1.2

Site ID	Date	Air temperature (˚C)	Surface temperature (˚C)	Wind speed Average (m/s)
C-30-N1	26th September 2023	22 to 24	21 to 23	0.5 to 0.9
C-40-N2	26th September 2023	20 to 23	20 to 30	0.3 to 1.8
D-30-N1	25th September 2023	21 to 24	31 to 34	0.4 to 0.8
D-20-N2	25th September 2023	23 to 27	29 to 30	0.3 to 1.3
D-20-N3	25th September 2023	18 to 19	17 to 18	0.7 to 1.4
E-20-N1	14th September 2023	23	32 to 37	0.5 to 1.0
E-30-N2	14th September 2023	22 to 23	34 to 39	0.3 to 1.7
E-30-N3	14th September 2023	17 to 21	23 to 33	<0.5
F-40-N1	13th September 2023	19 to 22	18 to 27	0.3 to 0.8
F-40-N2	13th September 2023	19 to 22	23 to 27	0.3 to 0.9
F-40-N3	13th September 2023	20	26 to 31	0.4 to 1.0
G-70-N1	17th November 2023	9 to 10	10 to 11	<0.5
G-60-N2	17th November 2023	9 to 10	10 to 11	<0.5
H-70-N1	23rd November 2023	15	10	0.3 to 0.7
H-70-N2	23rd November 2023	15	10	<0.5
I-70-N1	24th November 2023	12	7 to 8	1.7
I-70-N2	24th November 2023	9	6 to 9	0.9
I-70-N3	24th November 2023	12	8 -12	0.7
J-50-N1	1st December 2023	9	10	<0.5
J-50-N2	1st December 2023	4	3	<0.5
J-70-N3	1st December 2023	5	6	<0.5
K-60-N1	21st November 2023	9	9 to 11	<0.5
K-70-N2	21st November 2023	9	11	<0.5
K-70-N3	21st November 2023	9	9 to 10	<0.5

Site ID	Date	Air temperature (˚C)	Surface temperature (˚C)	Wind speed Average (m/s)
L-70-N1	15th December 2023	9 to 10	6 to 7	0.3 to 0.7
L-70-N2	15th December 2023	8 to 9	6 to 7	0.3 to 2.0
L-70-N3	15th December 2023	6 to 8	7 to 8	0.3 to 1.6
M-70-N1	30th November 2023	2	0.9	<0.5
M-70-N2	30th November 2023	4	2	<0.5
M-70-N3	30th November 2023	3	5	<0.5
N-70-N1	11th December 2023	10	10 to 11	<0.5
N-70-N2	11th December 2023	9 to 10	7 to 11	1.3 to 2.2
O-60-N1	6th December 2023	7 to 8	1 to 2	<0.5
O-60-N2	6th December 2023	4 to 11	2 to 10	<0.5
O-60-N3	6th December 2023	3 to 7	2 to 5	0.9 to 1.9
P-70-N1	20th February 2024	11 to 12	11 to 13	1.3 to 1.8
P-60-N2	20th February 2024	13	14	1.3
Q-70-N1	20th February 2024	13	14	2.1
Q-70-N2	23rd February 2024	8 to 9	8 to 10	0.6 to 2.2
R-60-N1	28th February 2024	5 to 6	4 to 5	3.3 to 6.0
S-70-N1	27th February 2024	6 to 7	11 to 12	1.1 to 1.6
T-60-N1	18th March 2021	10 - 12	12 -14	1.0 to 2.4
T-60-N2	18th March 2021	12	14	1.3 to 2.0
U-60-N1	19th March 2021	9	11	< 0.5
U-60-N2	19th March 2021	9	11	<0.5
V-50-N1	19th March 2021	11	14	0.4 to 0.6
V-50-N2	19th March 2021	11	12	<0.5
W-60-N1	22nd March 2021	8 to 14	13 to 22	0.5

Site ID	Date	Air temperature (˚C)	Surface temperature (˚C)	Wind speed Average (m/s)
W-60-N2	22nd March 2021	18	21 to 25	<0.5
X-60-N1	23rd March 2021	12 to 14	15 to 19	<0.5

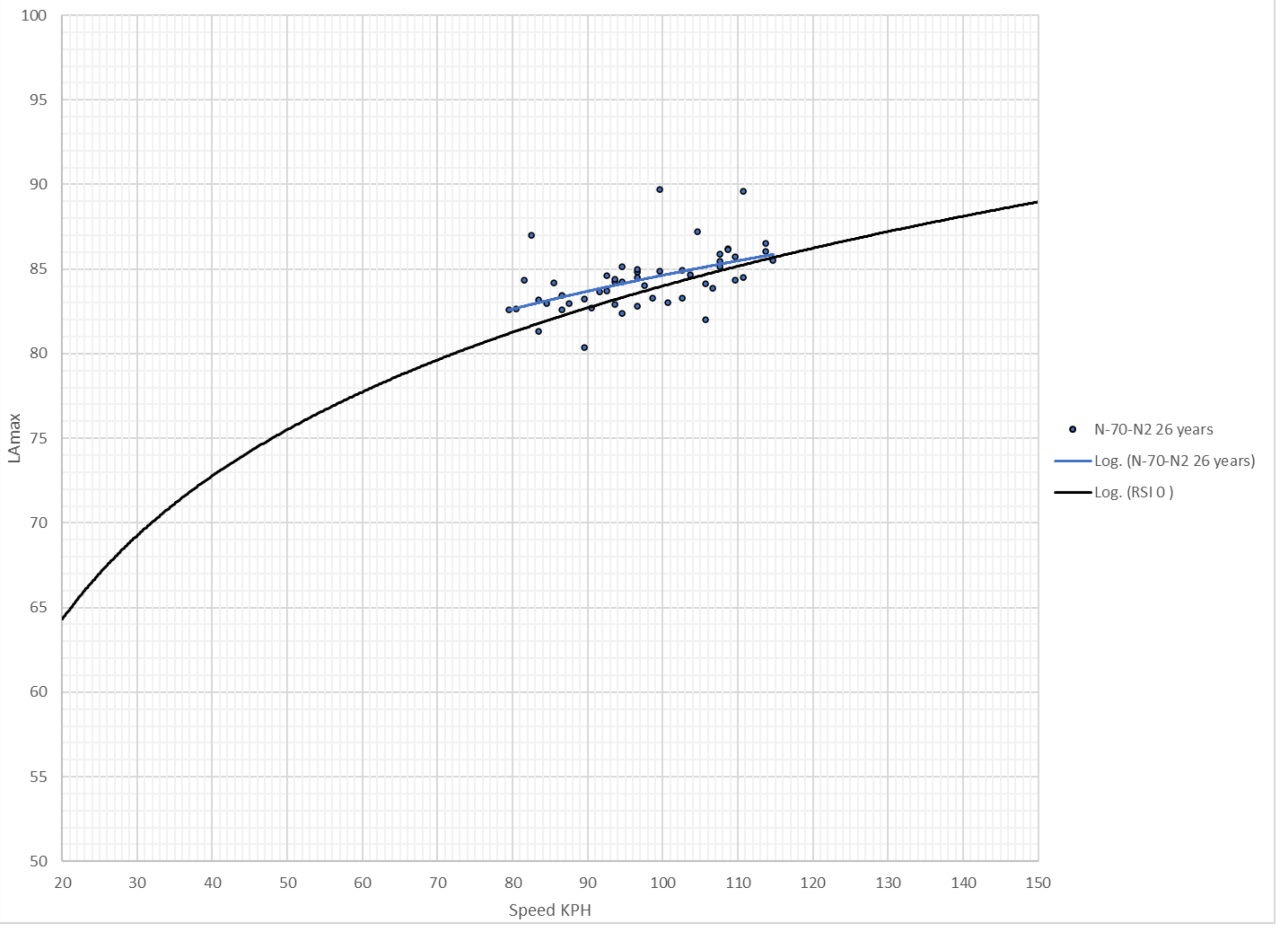
Table 11: Equipment used during the 2023/2024 surveys

Type	Model	Serial number	Laboratory Calibration date
Sound Level Meter	Rion NL-52	810570	13th December 2022 (valid for 2 years)
Sound Level Meter	Rion NL-52	420763	24th January 2023 (valid for 2 years)
Sound Level Meter	Rion NL-52	710387	18th December 2023 (valid for 2 years)
Calibrator	B&K 4231	2642980	4th January 2023 (valid for 1 year)
Calibrator	Rion NC-74	34304647	14th November 2023 (valid for 1 year)
Calibrator	B&K 4231	3005464	4th October 2023 (valid for 1 year)
Speed Gun	Bushnell: 1101911	N/A	N/A
Speed Gun	Tracer: SRA3000	N/A	N/A

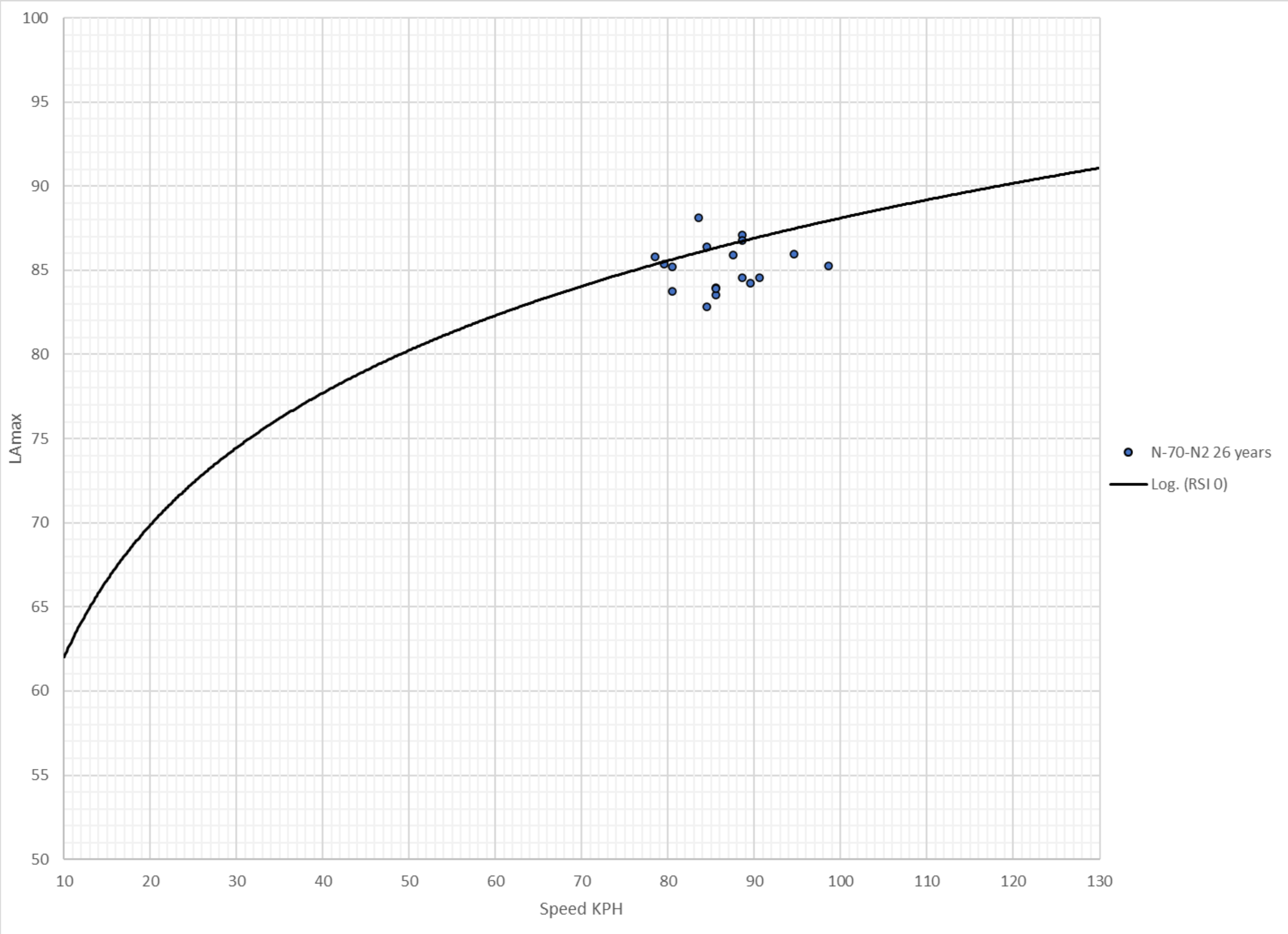
Appendix C Vehicle speed and L_{Amax} plots

The key in the following graphs refers to the site ID and surface age found in Table 9.

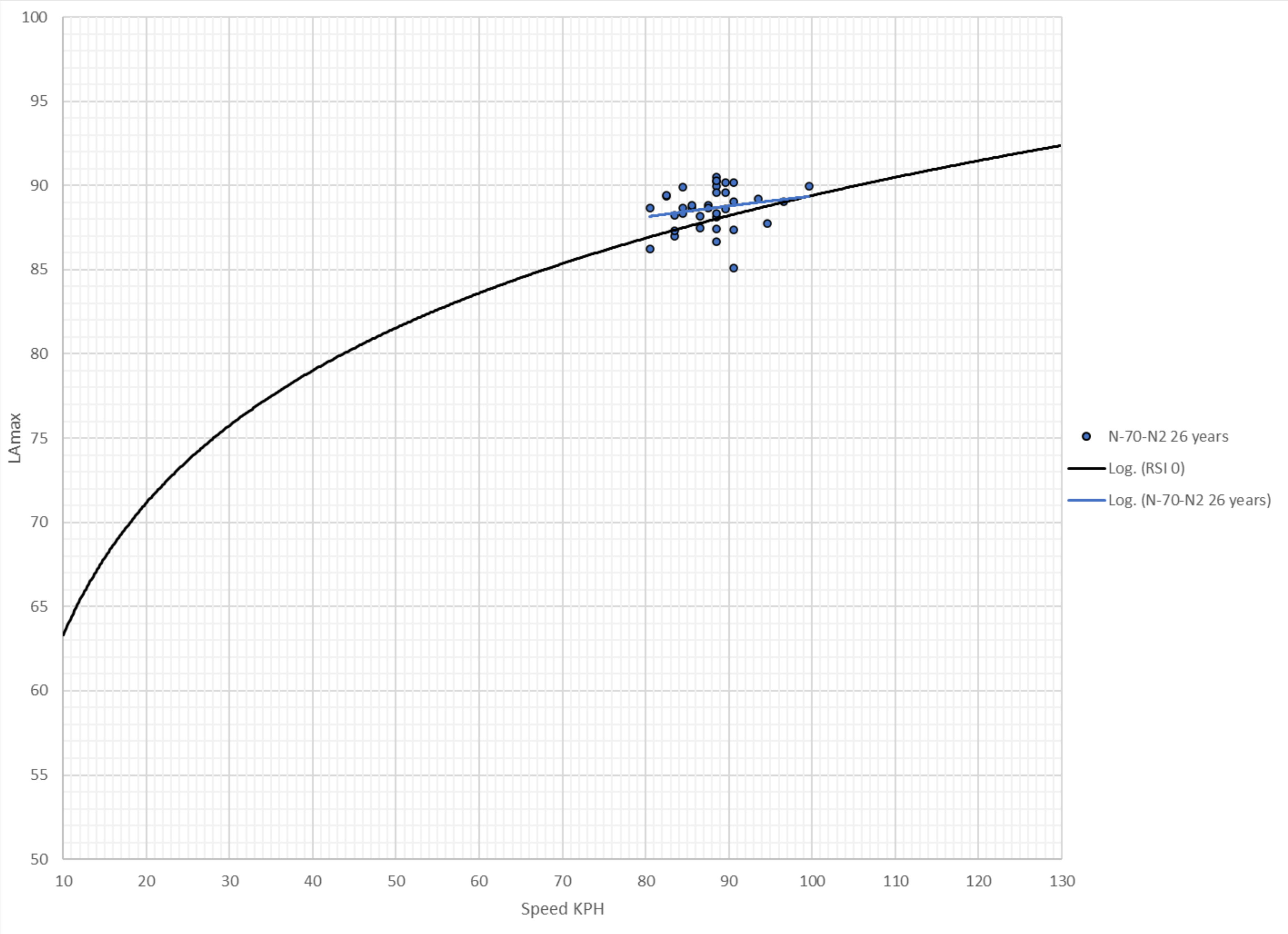
Surface Dressing – Light Vehicles



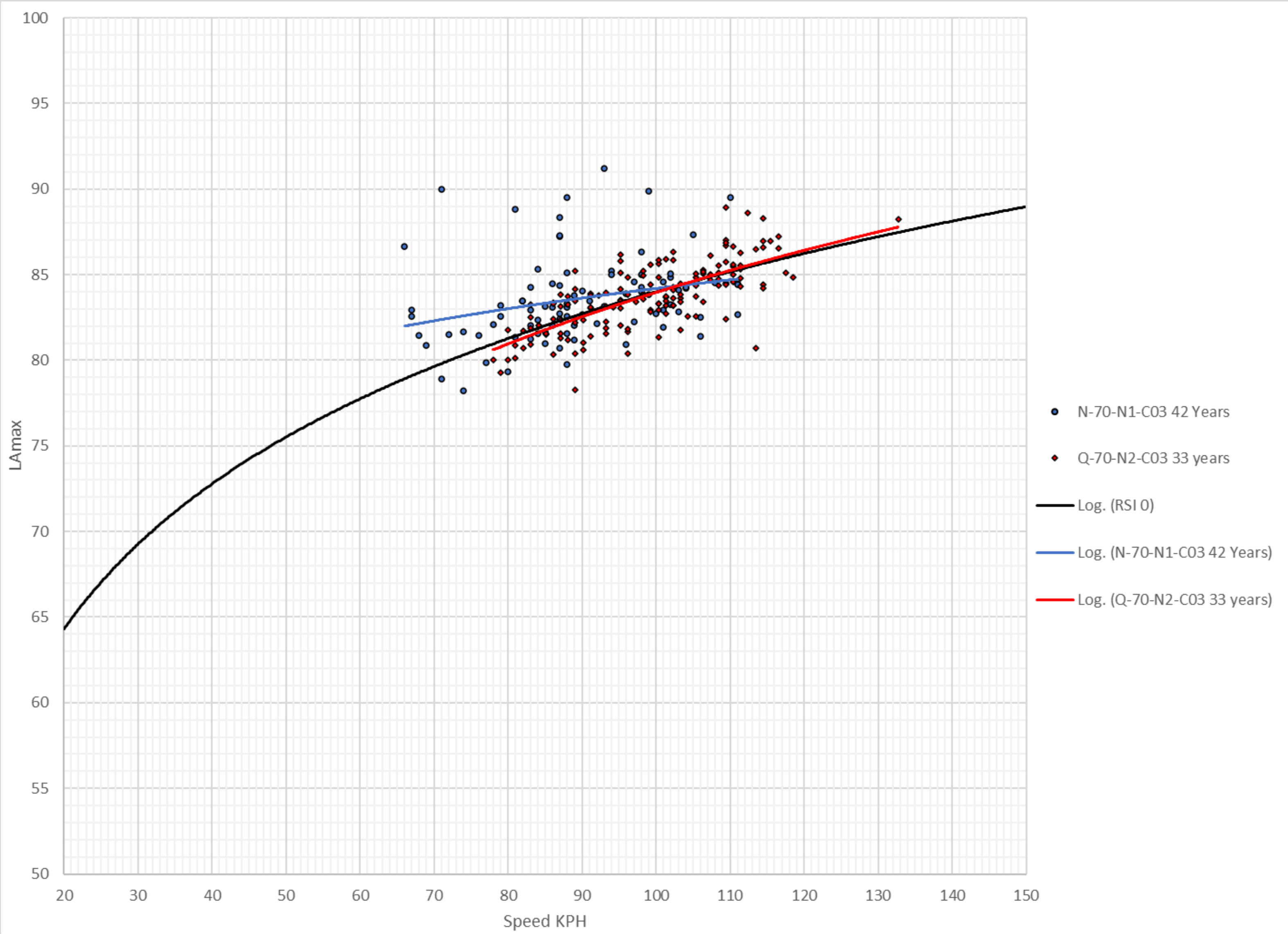
Surface Dressing – 2 Axle Heavy Vehicles



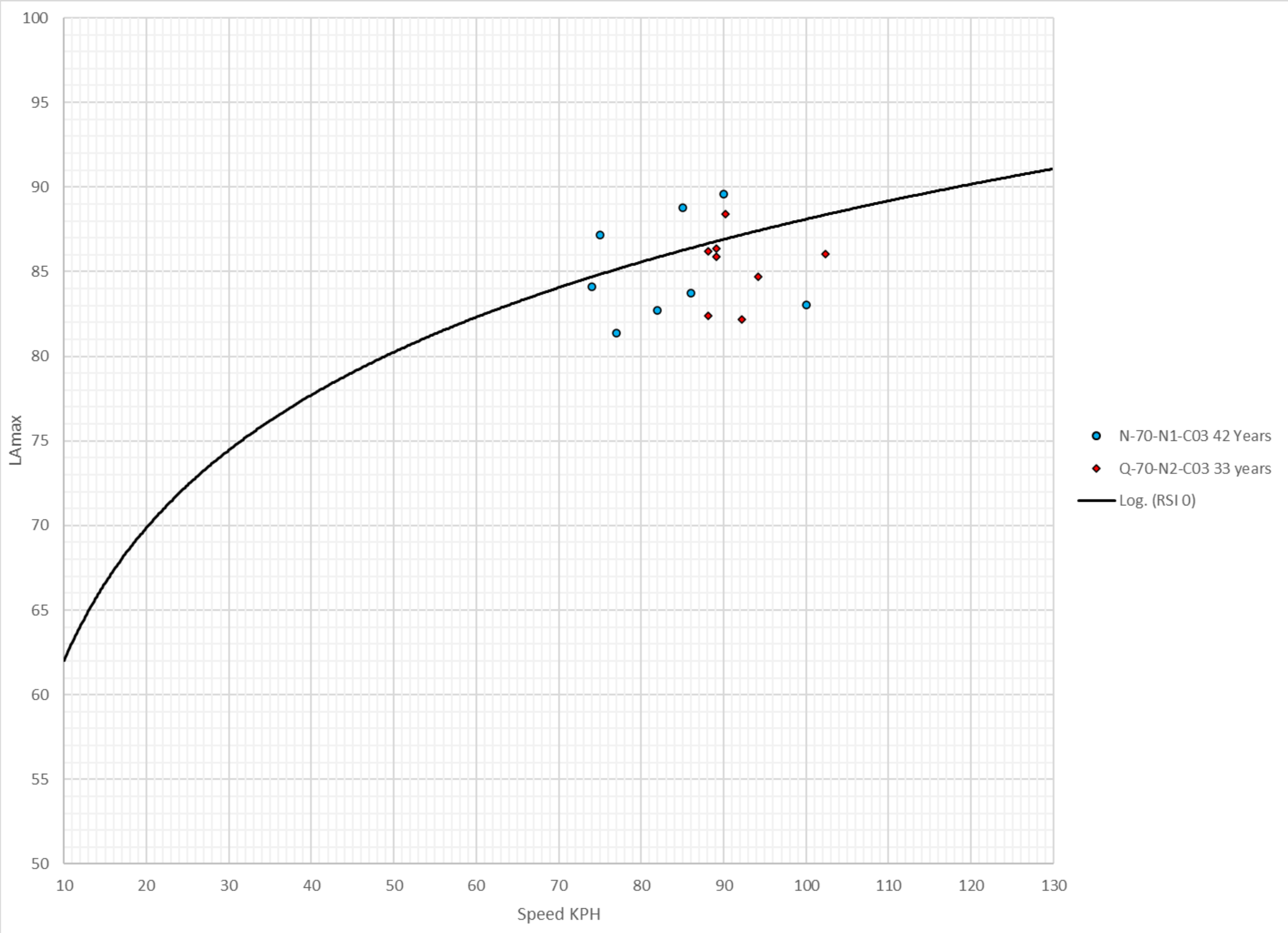
Surface Dressing - >2 Axle Heavy Vehicles



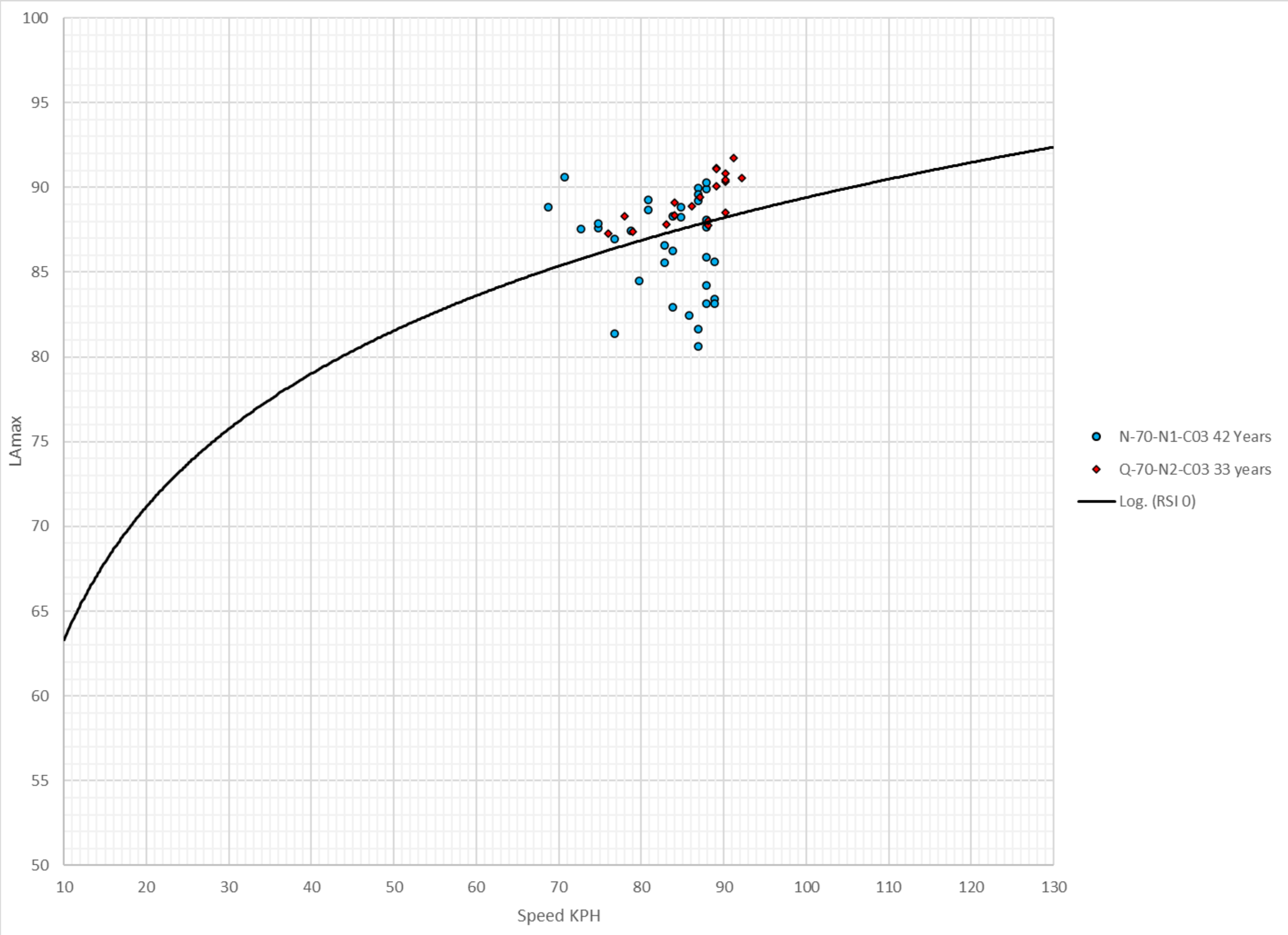
Brushed Concrete – Light Vehicles



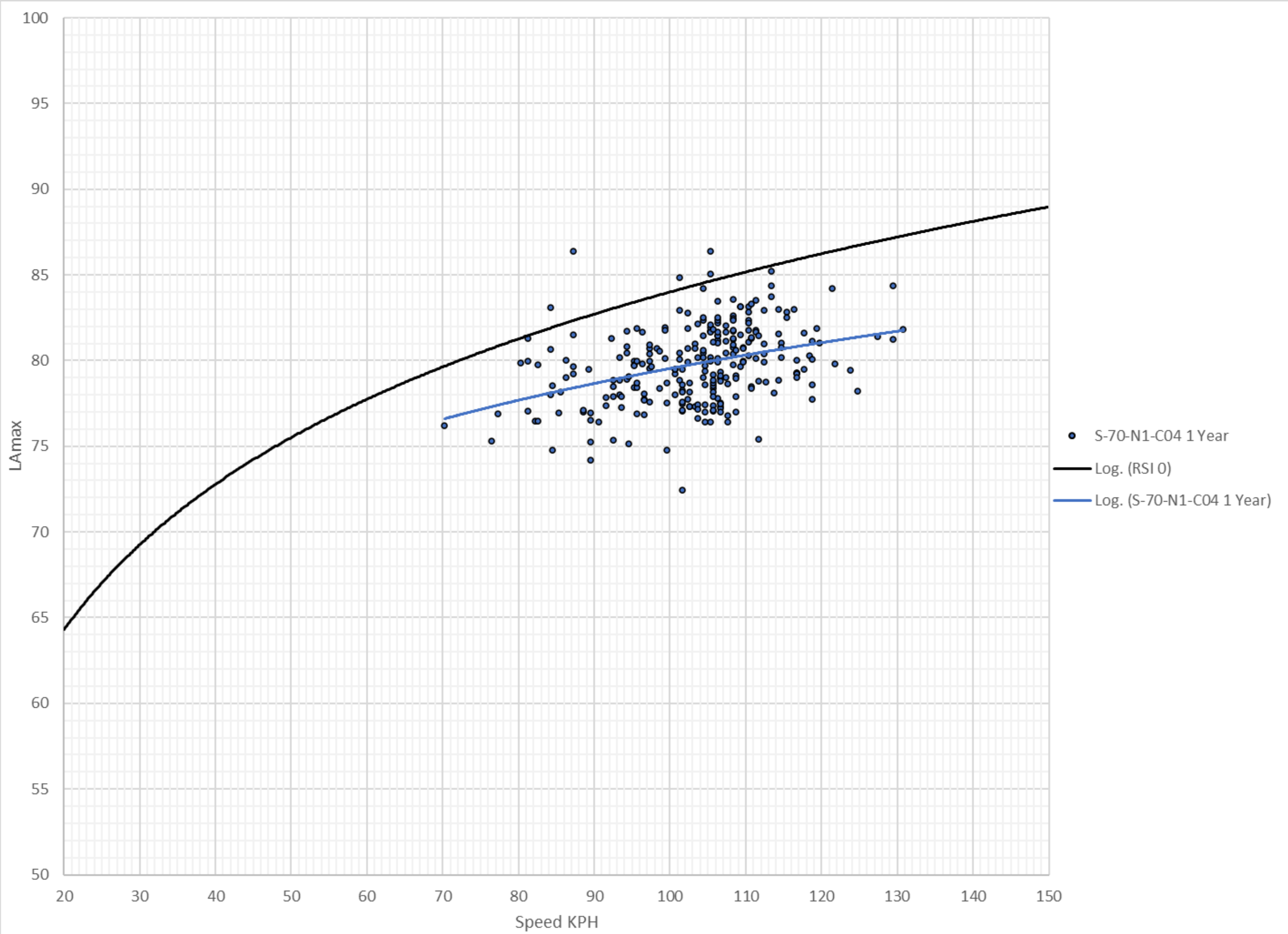
Brushed Concrete – 2 Axle Heavy Vehicles



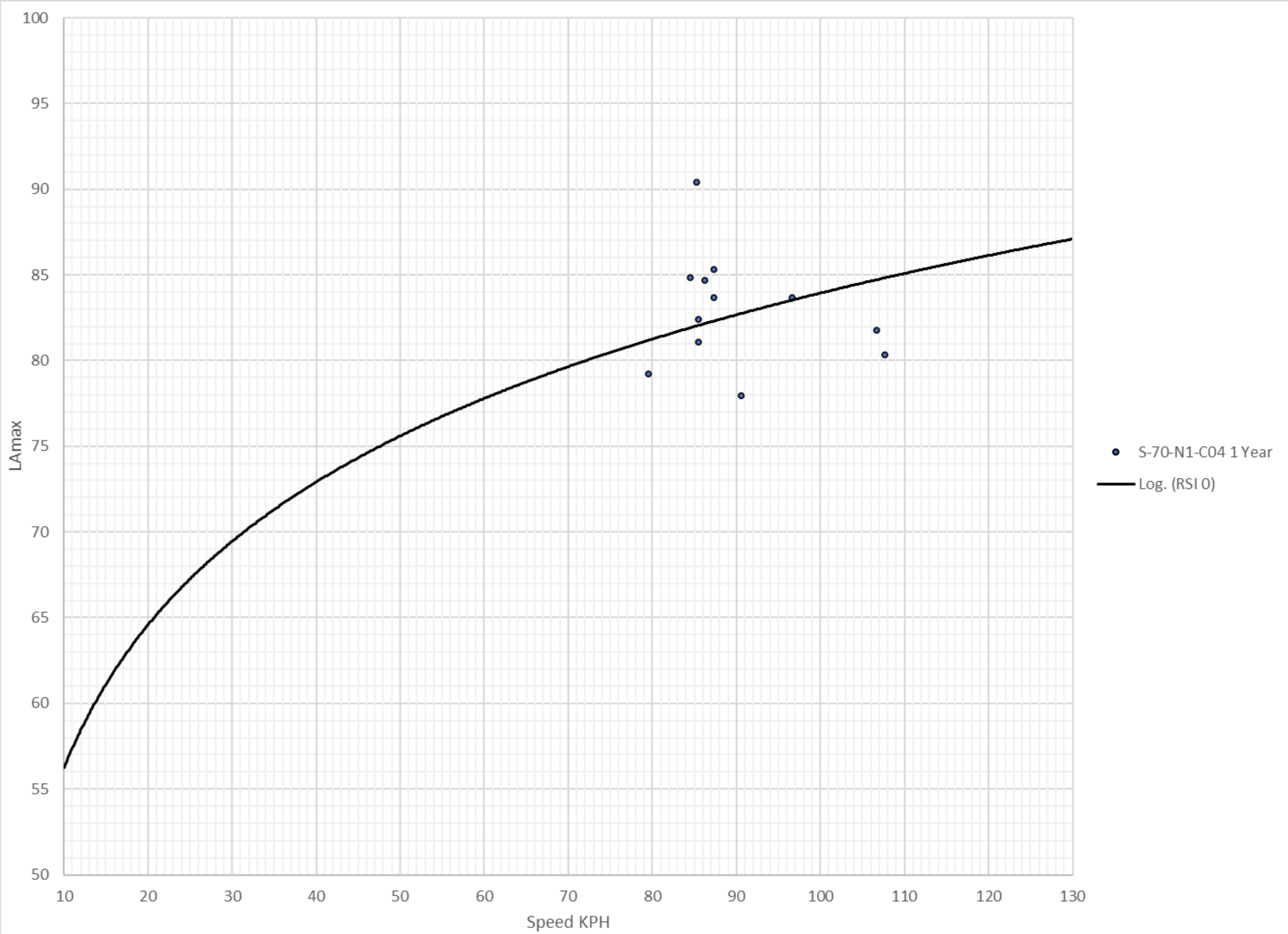
Brushed Concrete - >2 Axle Heavy Vehicles



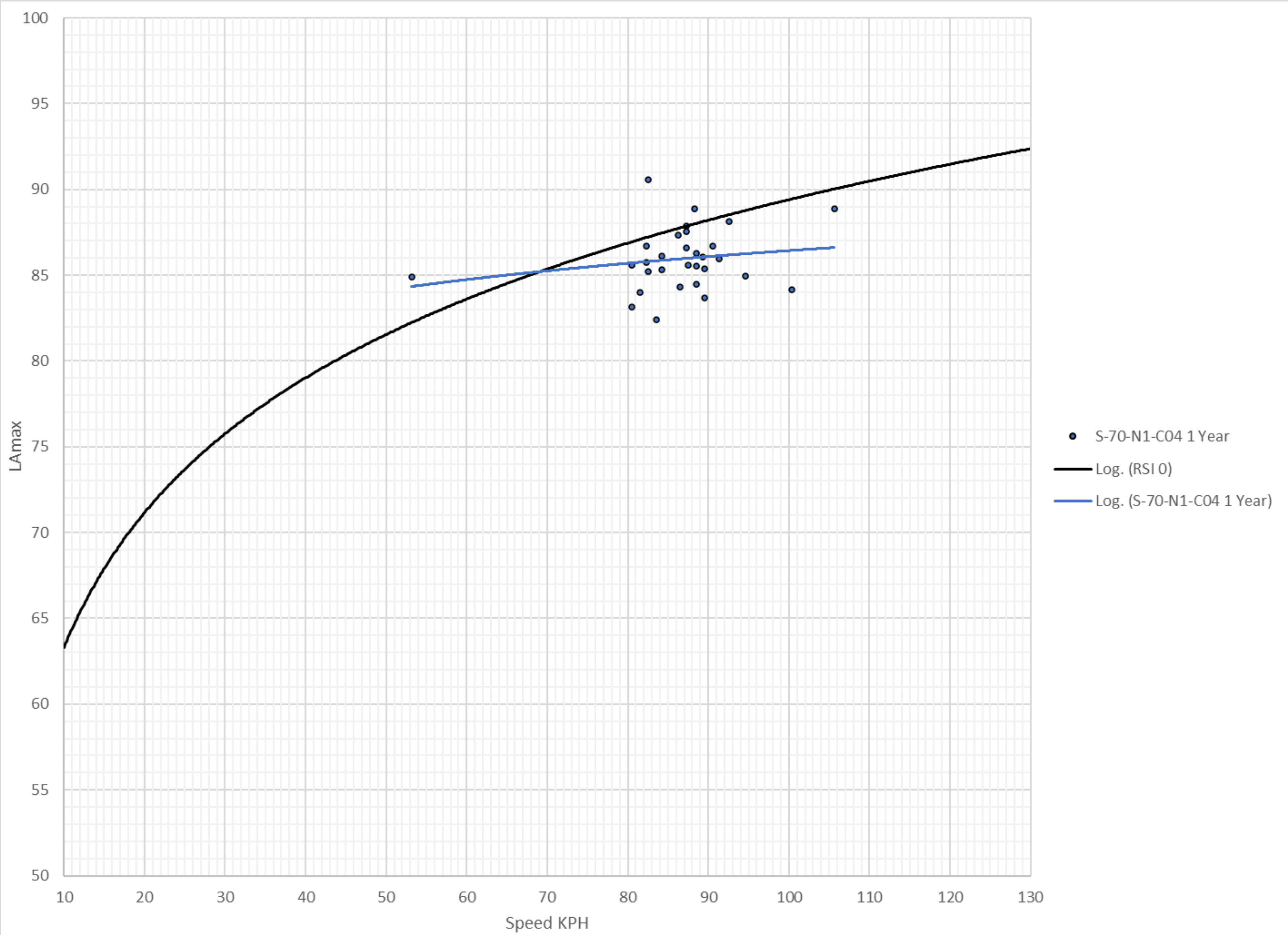
Thin Surface 6mm – Light Vehicles



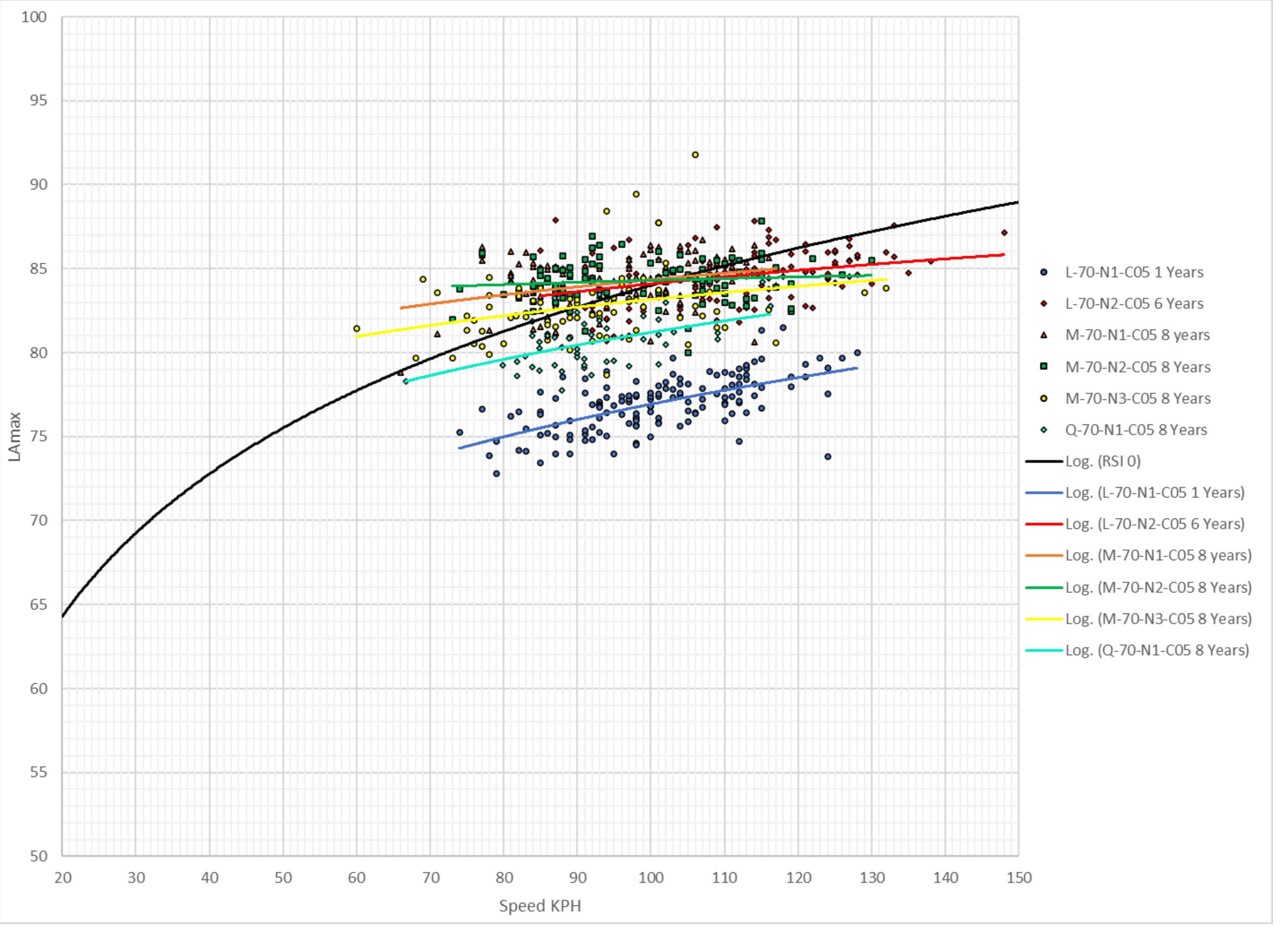
Thin Surface 6mm – 2 Axle Heavy Vehicles



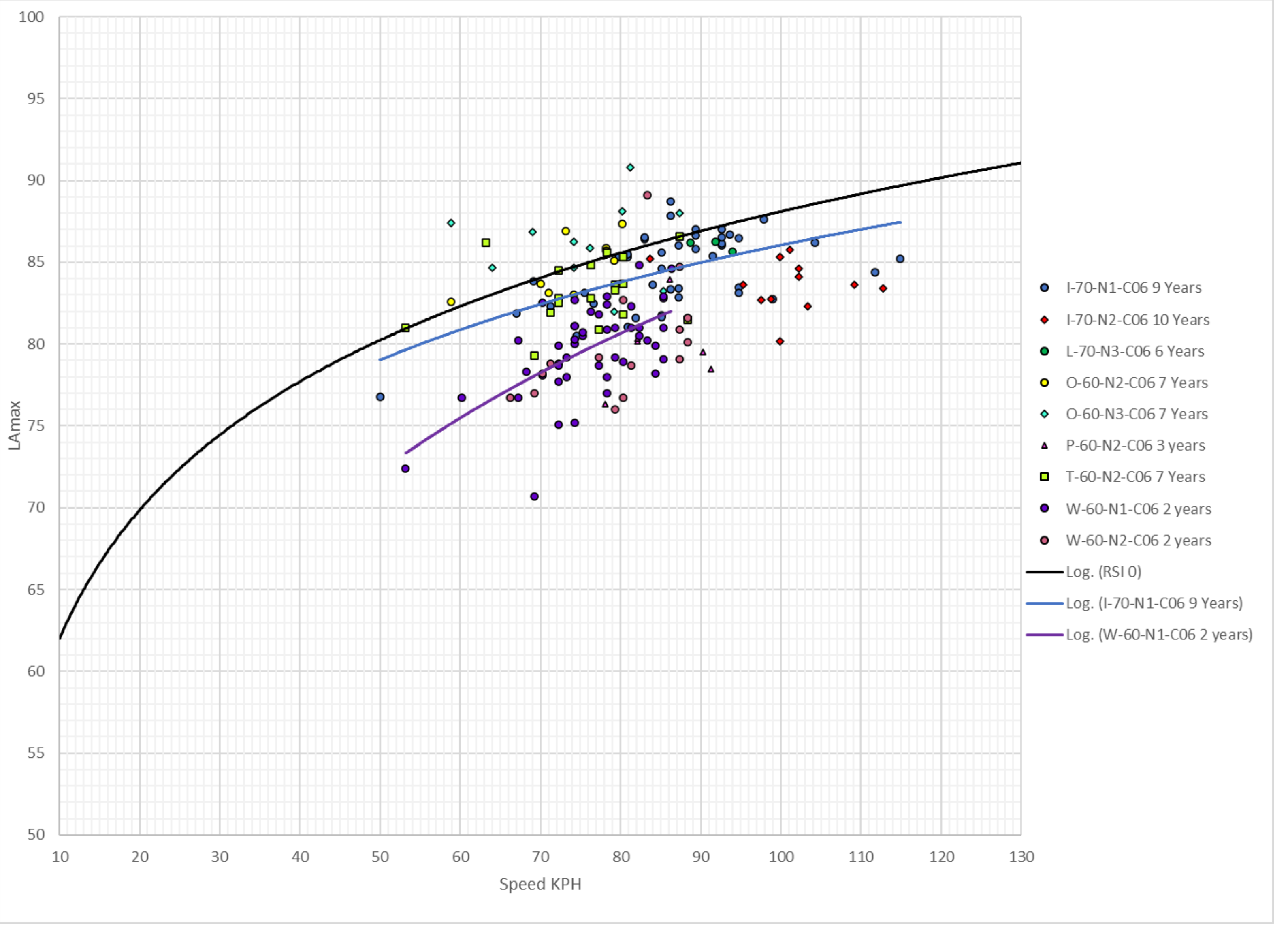
Thin Surface 6mm – >2 Axle Heavy Vehicles



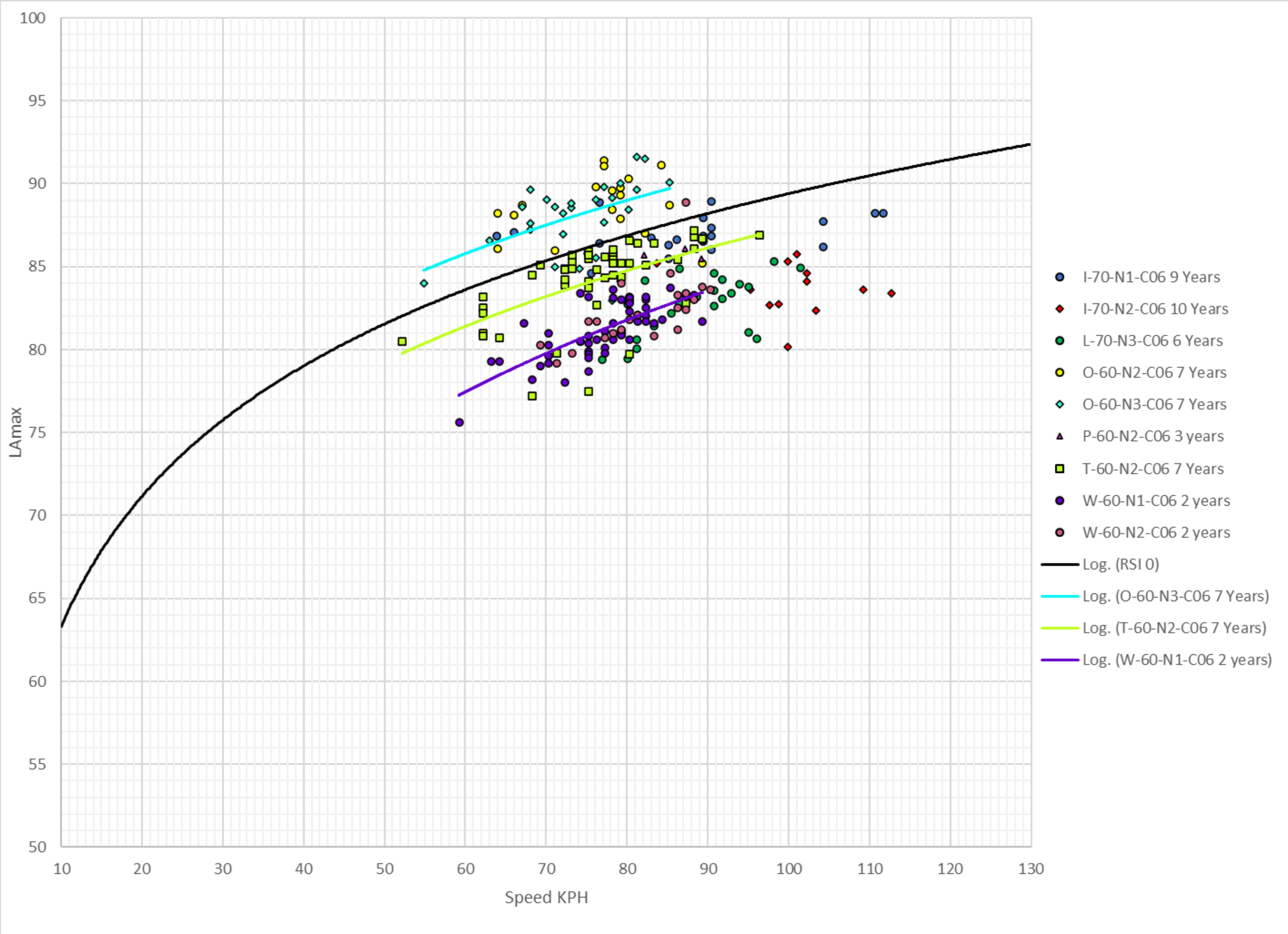
Thin Surface 10mm – Light Vehicles



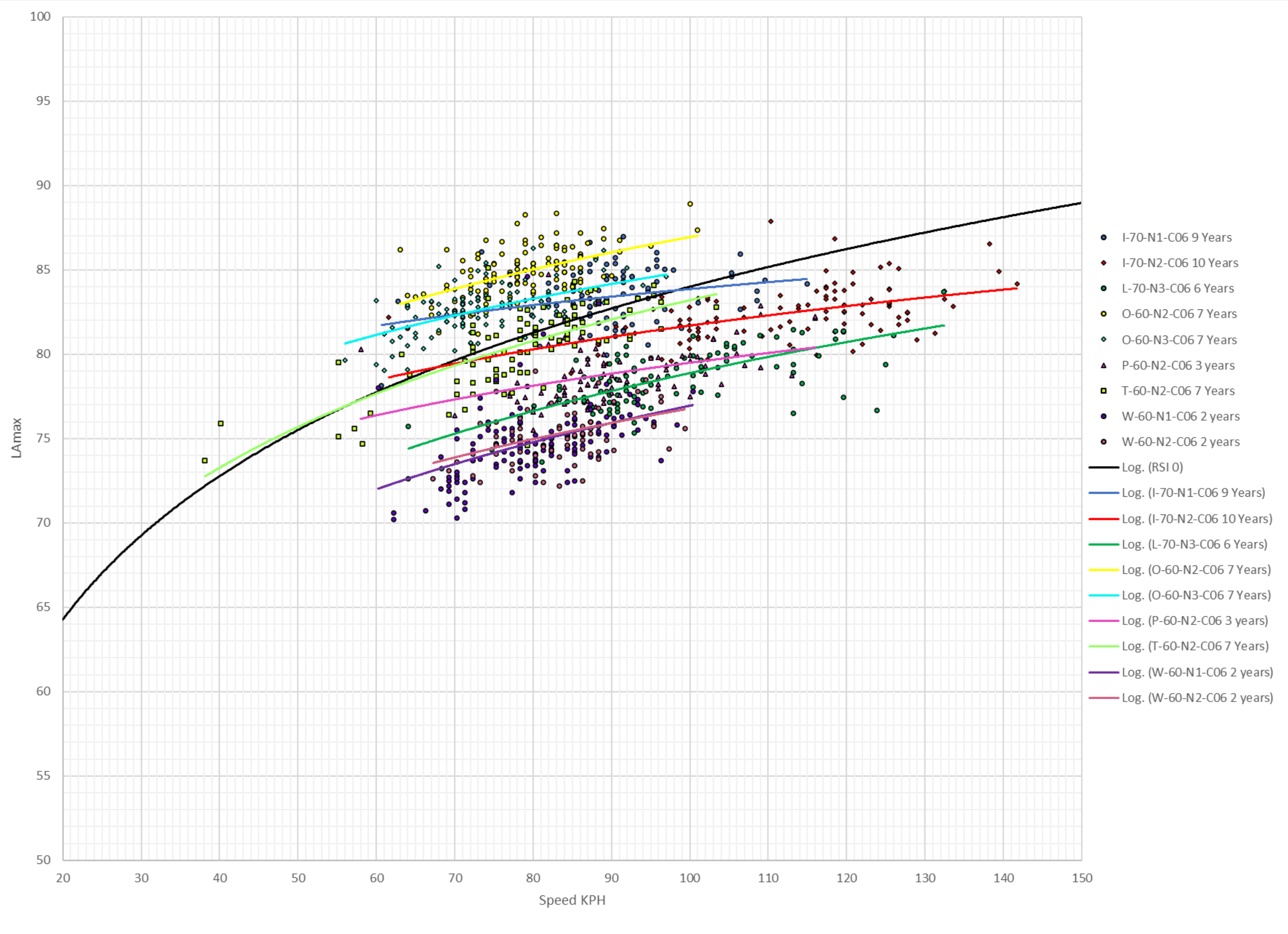
Thin Surface 10mm – 2 Axle Heavy Vehicles



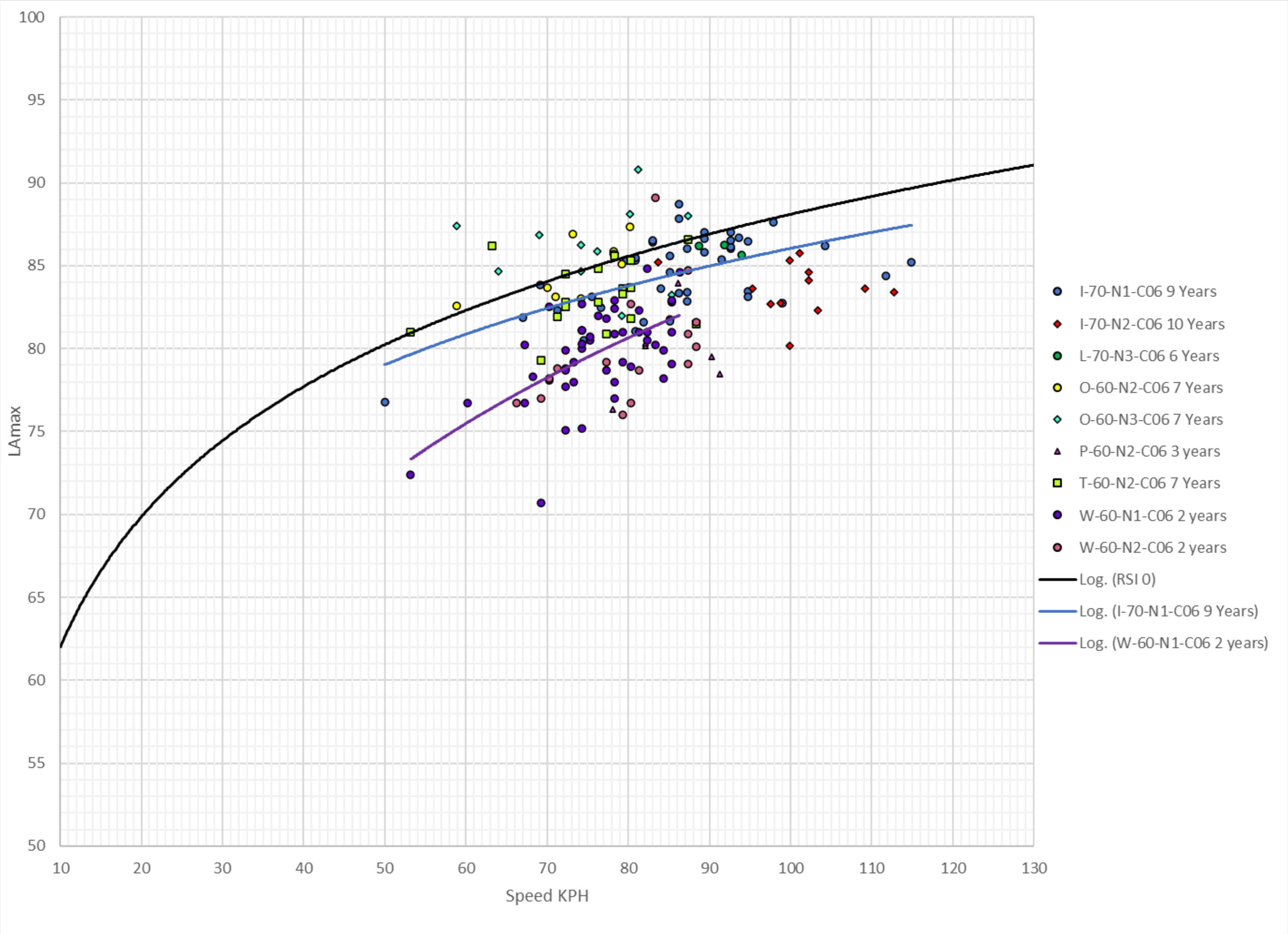
Thin Surface 10mm – >2 Axle Heavy Vehicles



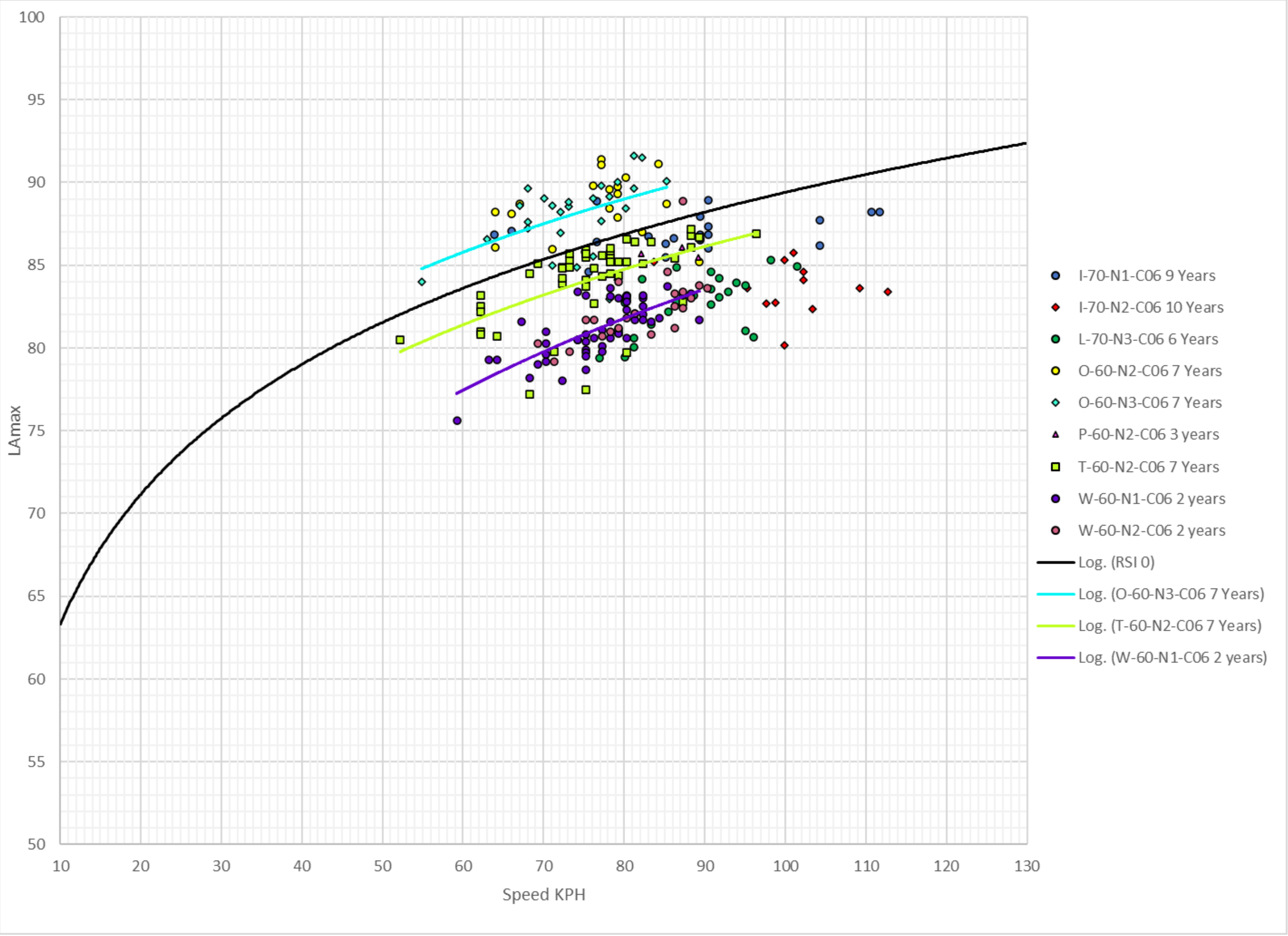
Thin Surface 14mm – Light Vehicles



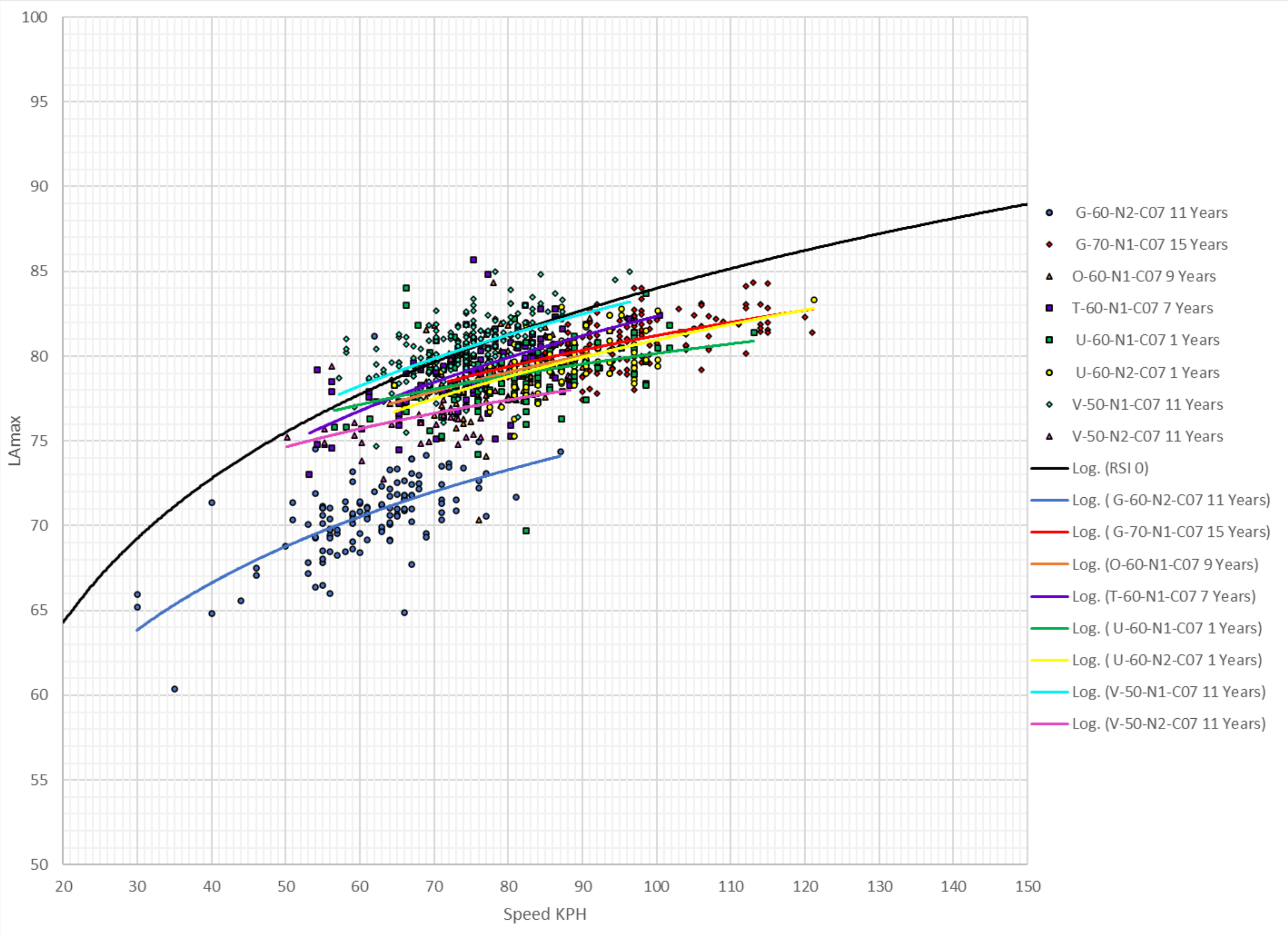
Thin Surface 14mm – 2 Axle Heavy Vehicles



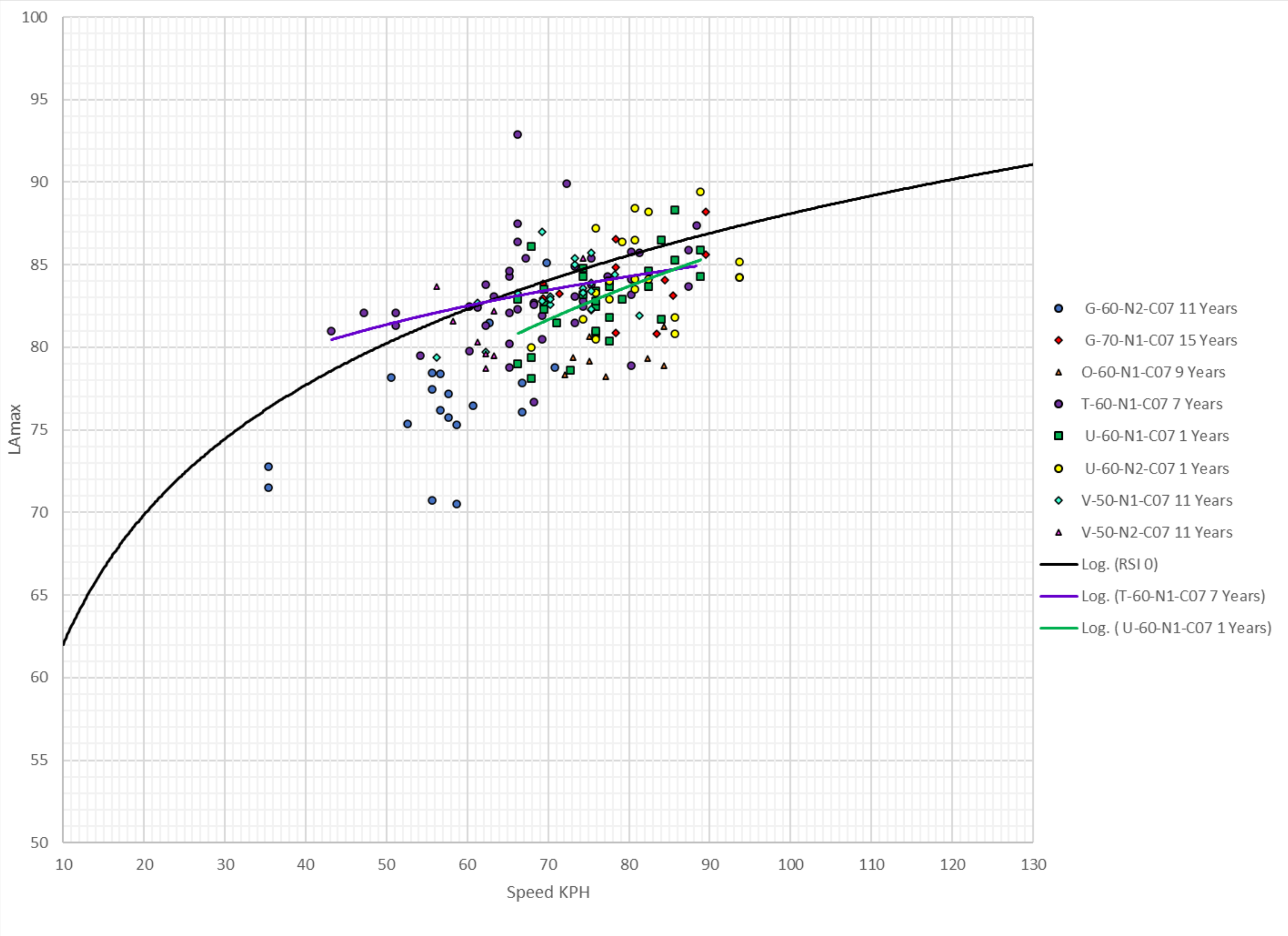
Thin Surface 14mm – >2 Axle Heavy Vehicles



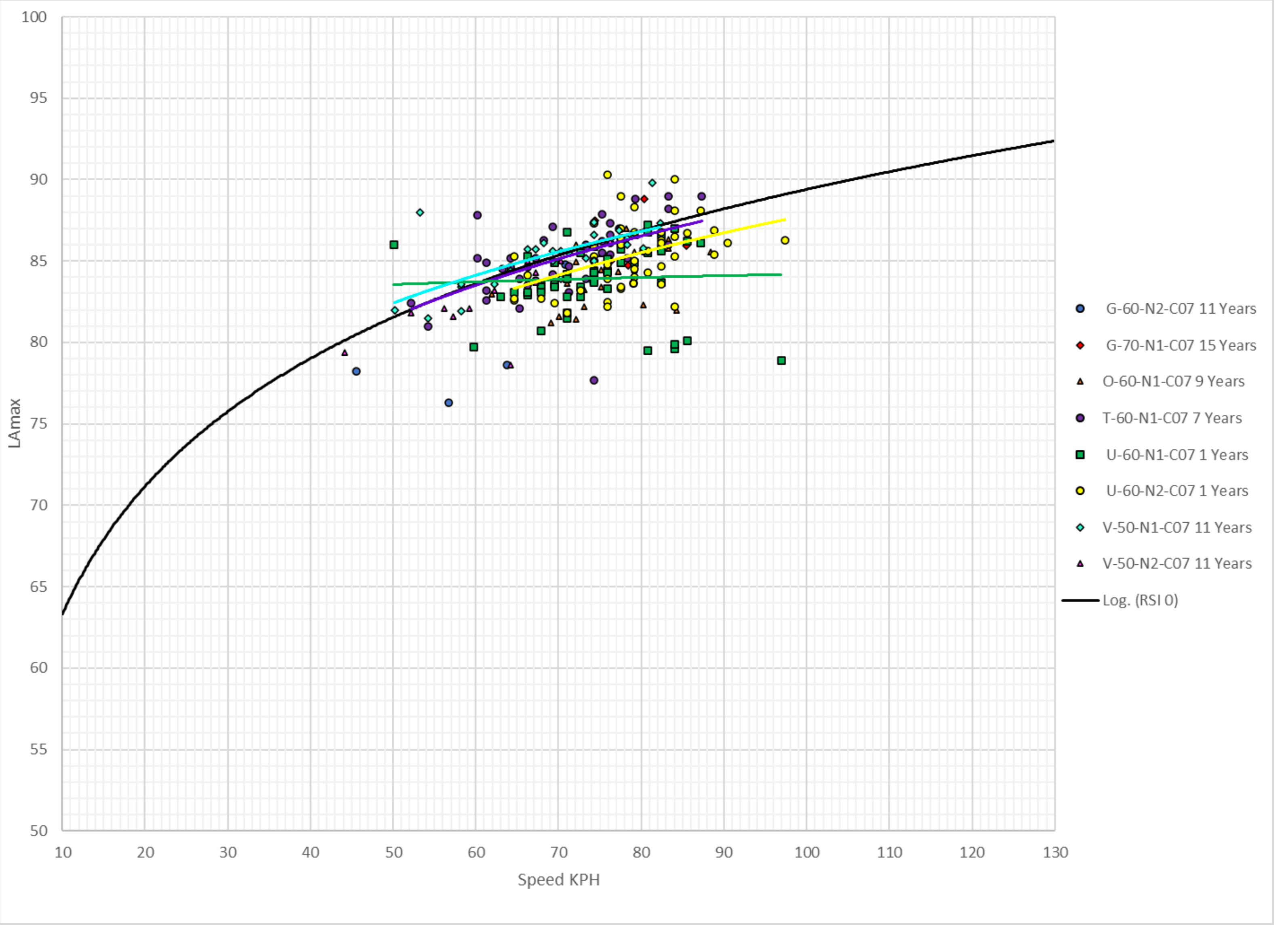
Thin Surface Unknown – Light Vehicles



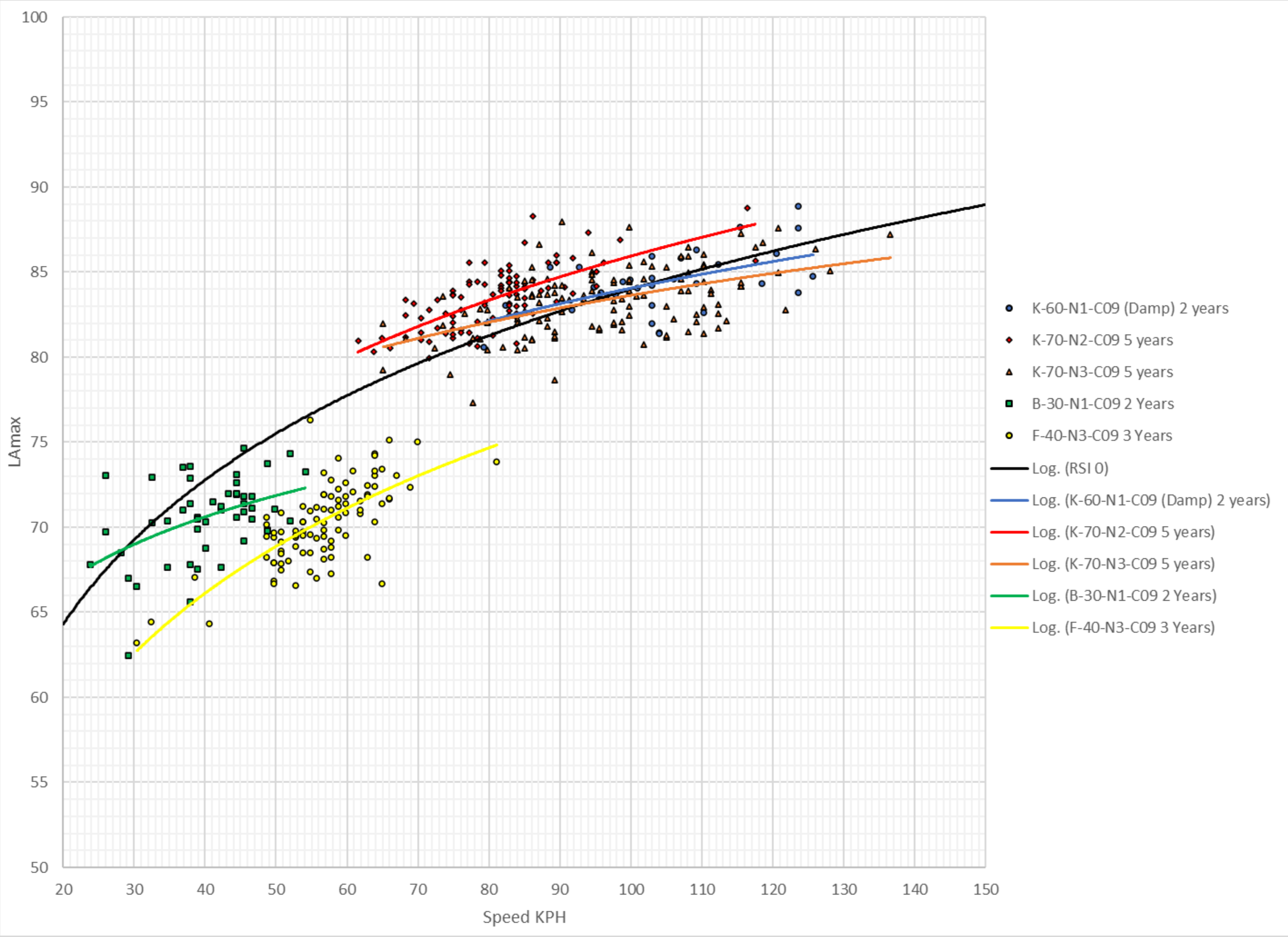
Thin Surface Unknown – 2 Axle Heavy Vehicles



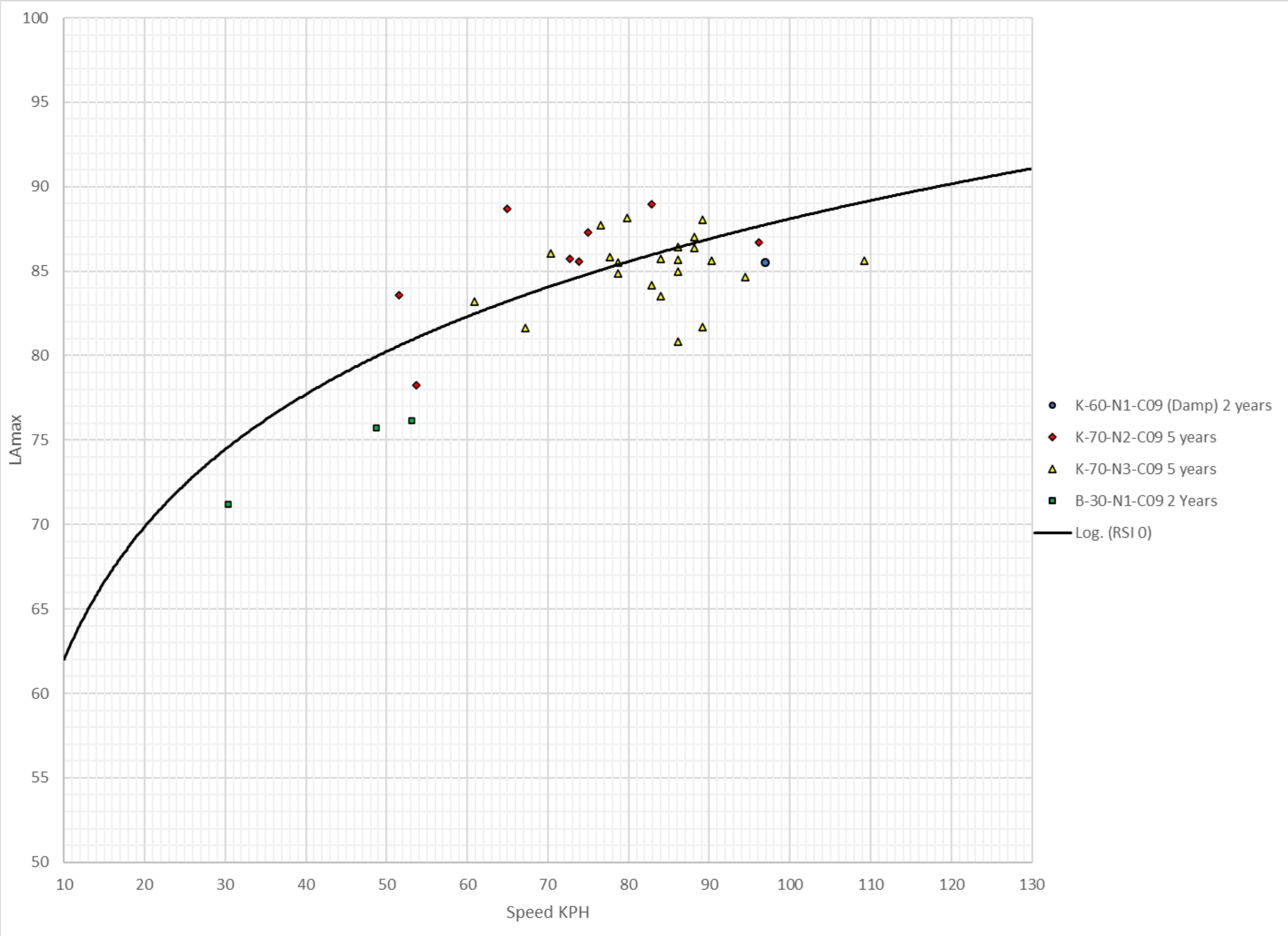
Thin Surface Unknown – >2 Axle Heavy Vehicles



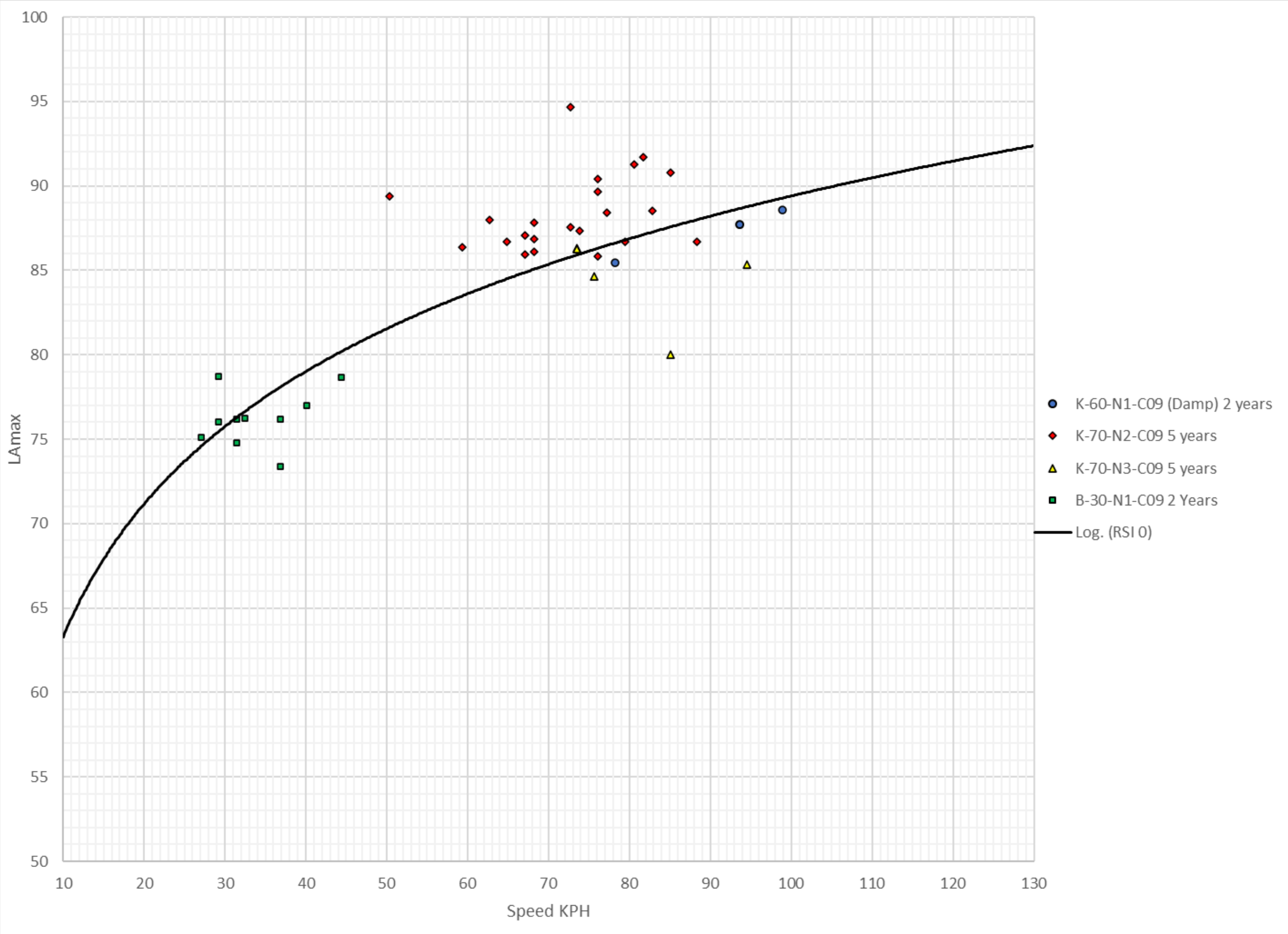
Stone Mastic Asphalt 10mm – Light Vehicles



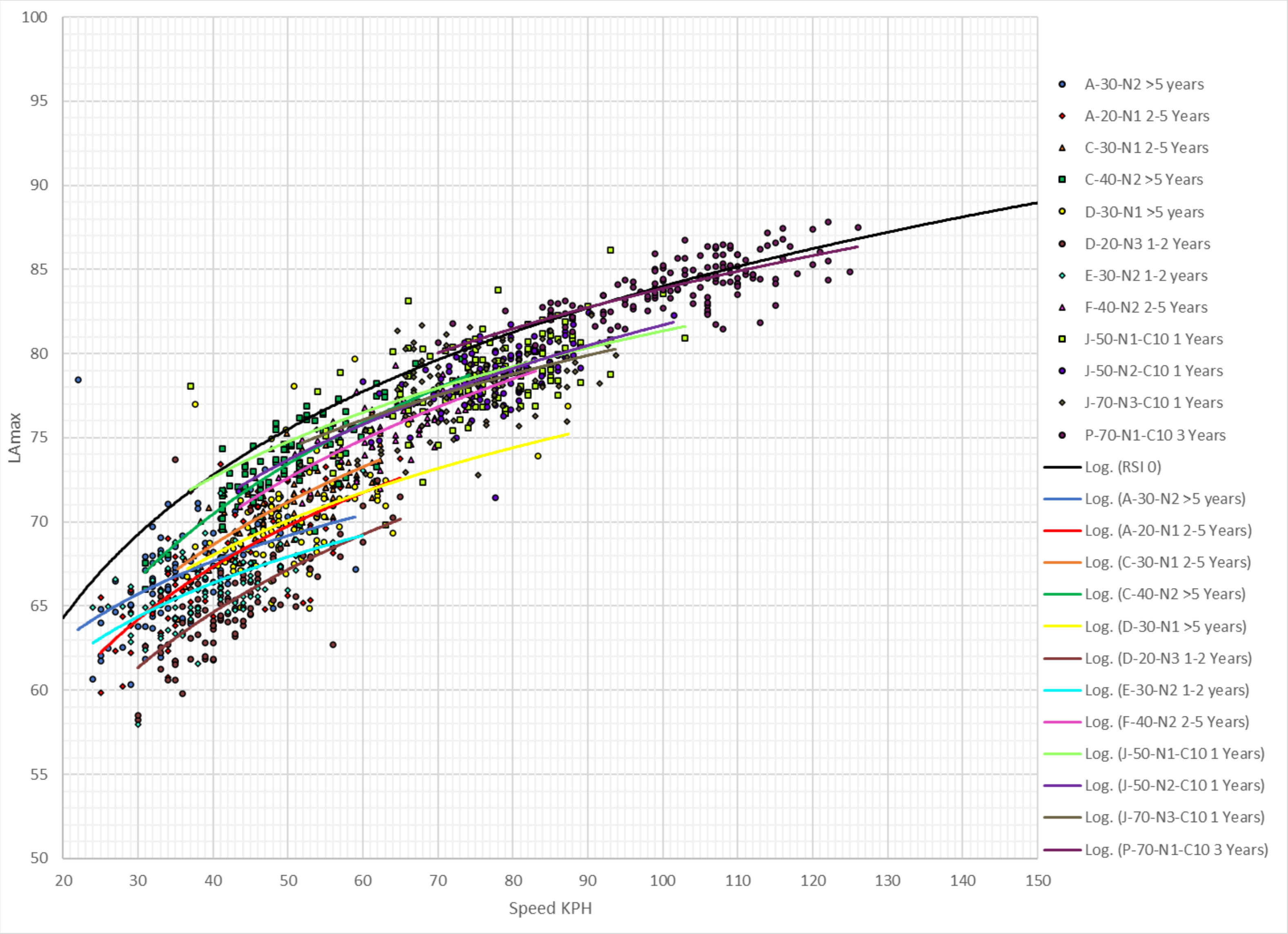
Stone Mastic Asphalt 10mm – 2 Axle Heavy Vehicles



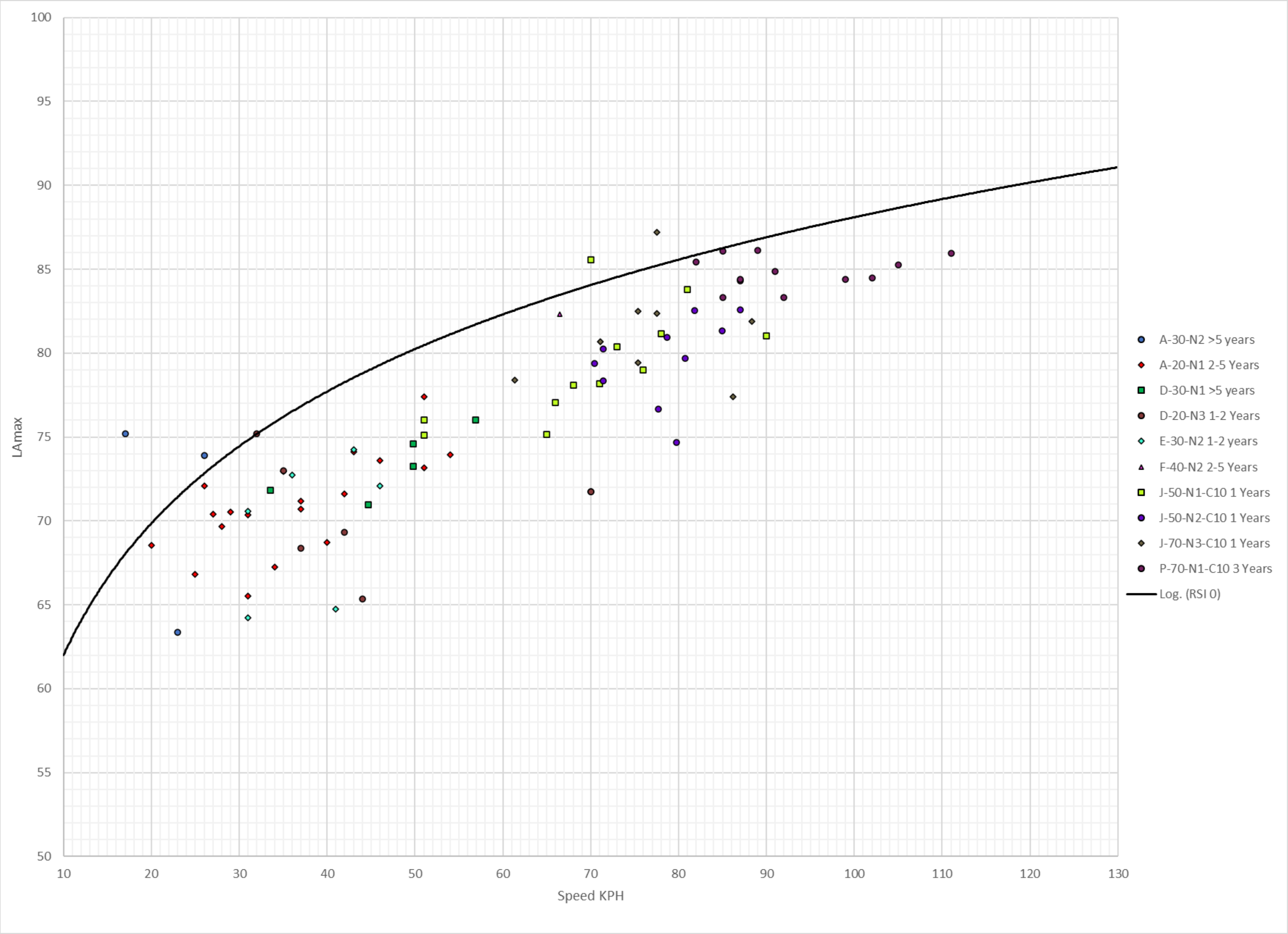
Stone Mastic Asphalt 10mm – >2 Axle Heavy Vehicles



Stone Mastic Asphalt 14mm – Light Vehicles

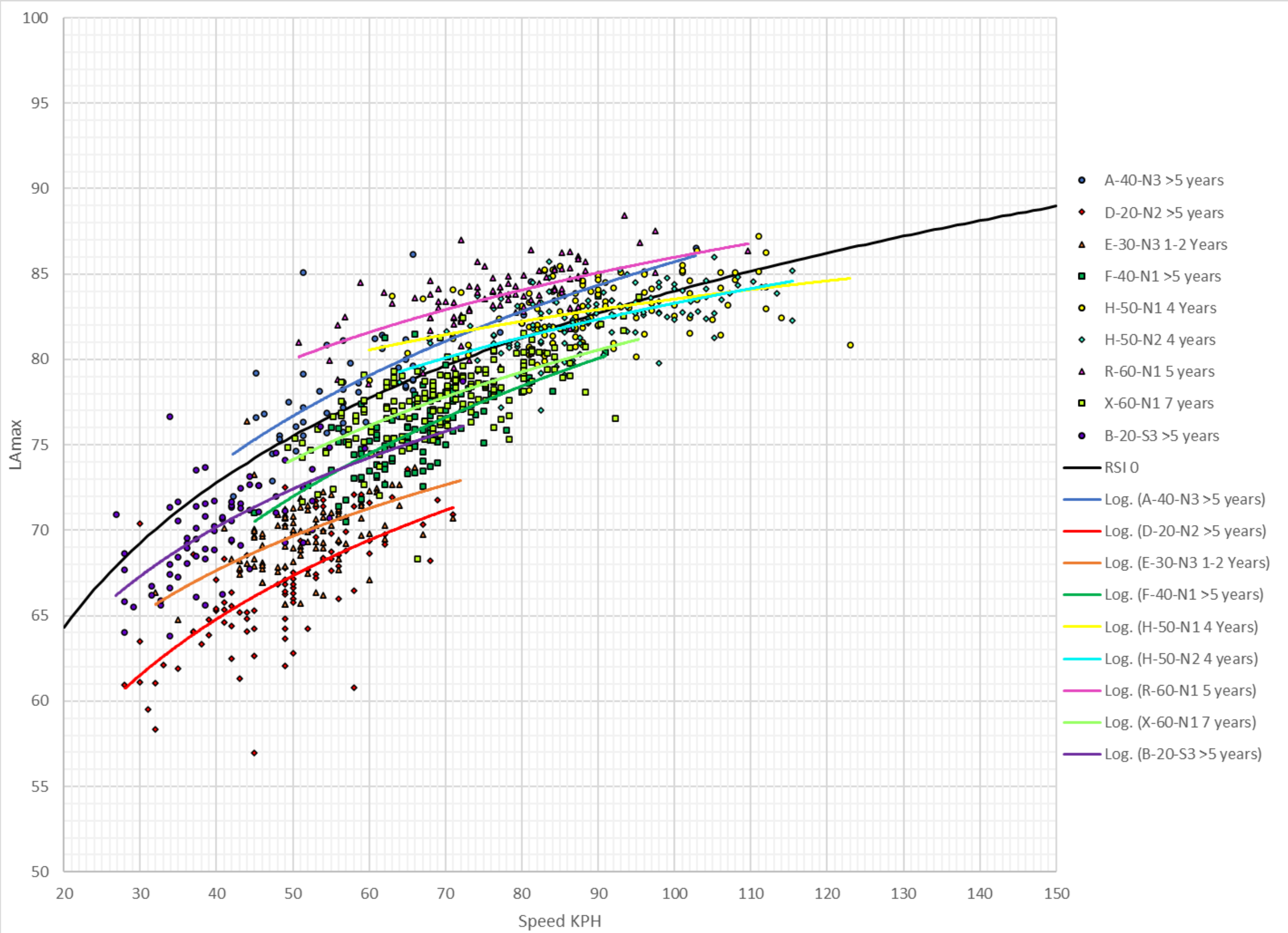


Stone Mastic Asphalt 14mm – 2 Axle Heavy Vehicles

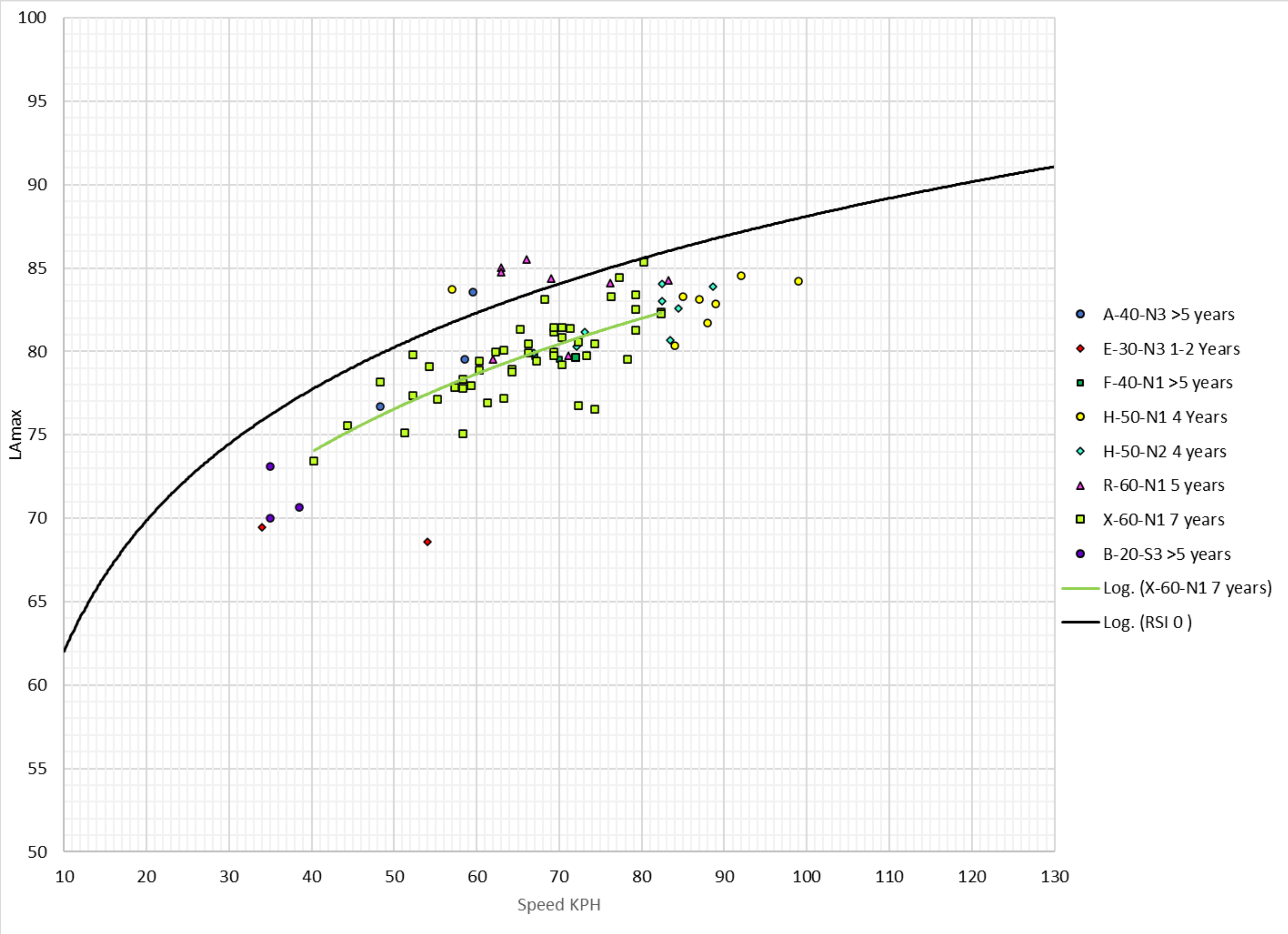


Stone Mastic Asphalt 14mm – >2 Axle Heavy Vehicles

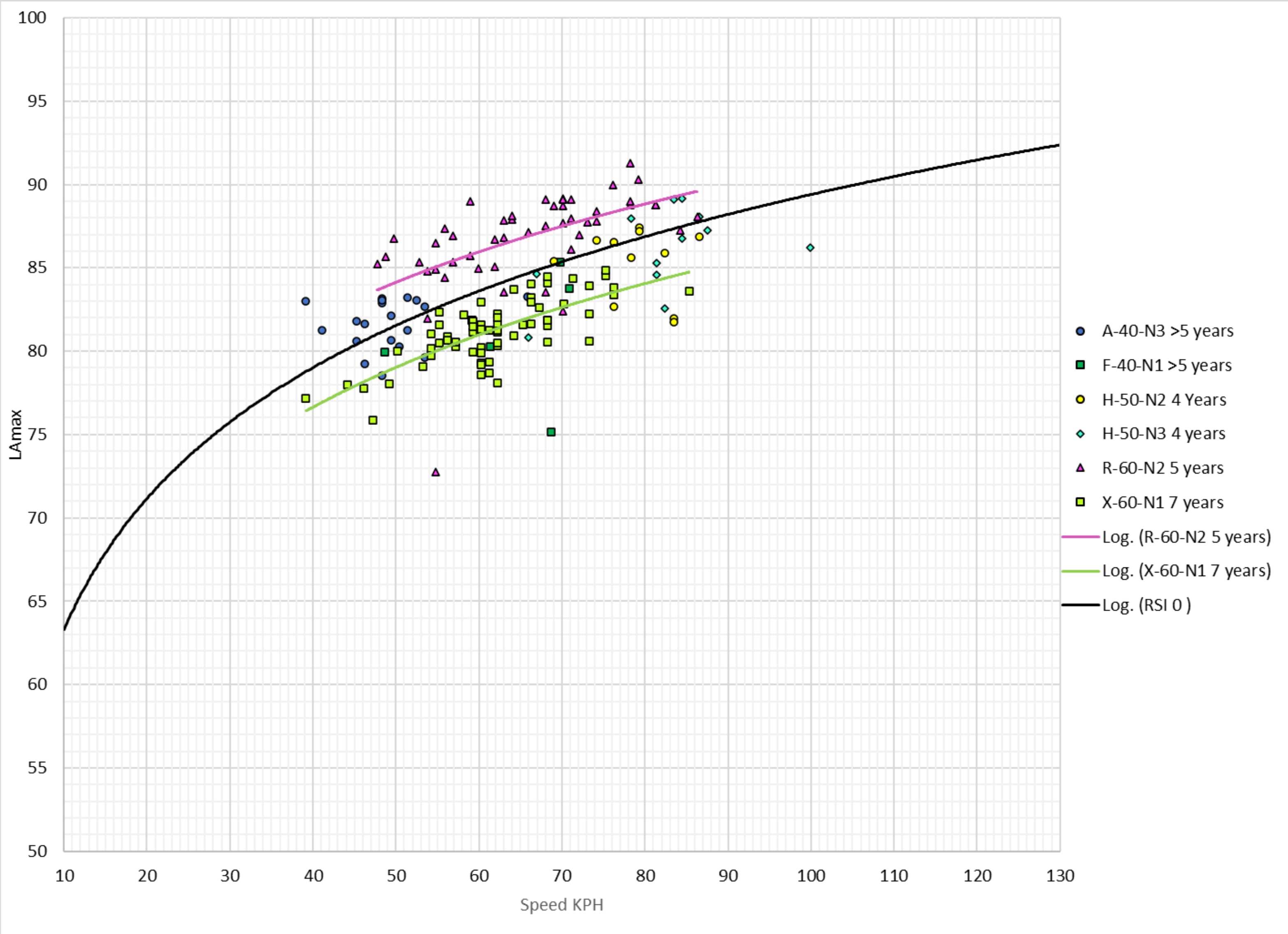
Hot Rolled Asphalt – Light Vehicles



Hot Rolled Asphalt – 2 Axle Heavy Vehicles



Hot Rolled Asphalt – >2 Axle Heavy Vehicles



Appendix D Revised coefficients

D.1 Core coefficients

The values of the coefficients in equations (**1**) and (**2**) for the vehicle categories presented in Table 7, are given in Table 12 to Table 16. No revisions to the coefficients for vehicle category 4 are proposed.

Table 12: Vehicle Category 1C

Coefficient	Value																										
	25 Hz	31 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
A_R	83.0	87.0	90.0	91.0	91.0	89.0	86.0	84.0	84.0	85.0	84.0	84.0	86.0	91.0	94.0	97.0	100	99.0	96.0	92.0	88.0	81.8	78.7	74.9	71.8	69.1	65.6
B_R	25.0	27.0	33.4	36.7	37.0	37.5	37.5	41.2	42.3	41.8	38.6	35.5	32.9	30.0	30.0	30.0	31.0	32.0	32.0	30.0	34.0	38.6	39.6	40.0	39.9	40.2	40.3
A_P	81	80	81	85	87	87	86	87	87	87	89	88	87	86	85	82	83	86	87	86	84	82	80	77	75	73	70
B_P	8	8	8	8	8	8	8	6	6	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Table 13: Vehicle Category 1V

Coefficient	Value																										
	25 Hz	31 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
A_R	83.0	87.0	90.0	91.0	91.0	89.0	86.0	84.0	84.0	85.0	84.0	84.0	86.0	91.0	94.0	97.0	100	99.0	96.0	92.0	88.0	81.8	78.7	74.9	71.8	69.1	65.6
B_R	25.0	27.0	33.4	36.7	37.0	37.5	37.5	41.2	42.3	41.8	38.6	35.5	32.9	30.0	30.0	30.0	31.0	32.0	32.0	30.0	34.0	38.6	39.6	40.0	39.9	40.2	40.3
A_P	81	80	81	85	87	87	86	87	88	88	90	89	88	87	85	82	83	86	87	86	84	82	80	77	75	73	70
B_P	8	8	8	8	8	8	8	6	6	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Table 14: Vehicle Category 1CE

Coefficient	Value																										
	25 Hz	31 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
A_R	83.0	87.0	90.0	91.0	91.0	89.0	86.0	84.0	84.0	85.0	84.0	84.0	86.0	91.0	94.0	97.0	100	99.0	96.0	92.0	88.0	81.8	78.7	74.9	71.8	69.1	65.6
B_R	25.0	27.0	33.4	36.7	37.0	37.5	37.5	41.2	42.3	41.8	38.6	35.5	32.9	30.0	30.0	30.0	31.0	32.0	32.0	30.0	34.0	38.6	39.6	40.0	39.9	40.2	40.3
A_P	75	73	73	76	77	79	79	81	79	78	80	75	70	66	65	63	63	66	67	68	67	66	65	62	59	57	54
B_P	8	8	8	8	8	8	8	6	6	7	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8

Table 15: Vehicle Category 2

Coefficient	Value																										
	25 Hz	31 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
A_R	95	96	95	92	91	90	90	92	92	92	94	96	99	101	102	103	102	98	95	91	87	84	81	79	78	77	75
B_R	23.8	28.4	31.1	35.4	35.9	36.7	36.3	35.9	38.1	36.5	33.5	30.6	27.7	21.9	23.8	28.4	31.1	35.4	35.0	35.0	35.0	35.0	36.0	36.0	36.0	36.0	36.0
A_P	92.1	92.5	94.1	94.5	92.4	92.0	91.0	91.9	91.0	93.4	94.4	94.2	93.0	90.8	92.1	92.5	94.1	94.5	92.4	90.1	87.6	85.8	83.8	81.4	80.0	77.2	75.4
B_P	6.5	6.5	6.5	6.5	6.5	6.5	6.5	5	5.5	6	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Table 16: Vehicle Category 3

Coefficient	Value																										
	25 Hz	31 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25 kHz	1.6 kHz	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10 kHz
A_R	97.3	98	95.6	93.2	91.9	90.0	91.0	91.0	92.0	93.0	94.0	97.0	101	104	105	104	102	97.5	93.0	89.0	85.5	84.1	82.2	79.8	78.6	77.5	76.8
B_R	25.9	30.4	32.3	36.5	36.8	38.0	36.8	32.8	36.0	34.6	32.7	29.3	26.4	26.0	28.0	30.4	32.3	36.5	36.8	38.0	36.8	38.5	38.9	38.5	40.2	40.8	41.0
A_P	96.8	95.1	95.8	95	92.7	91.2	90.0	93.0	95.0	95.0	97.0	97.2	95.8	95.9	96.8	95.1	95.8	95	92.7	91.2	88.7	87.6	87.2	84.2	82.7	79.7	77.6
B_P	5	5	5	5	5	5	5	3	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

D.2 Road surface corrections

The coefficients for the road surface corrections are provided in Table 17 for category 1 vehicles and Table 18 for category 2 and 3 vehicles. With respect to an initial release of the revised method, corrections are only applied in the 1/3rd octave bands used in the IMAGINE method. Corrections in other 1/3rd octave bands are set to zero.

Table 17: Vehicle Category 1

Road Surface	α													β
	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25kHz	1.6 kHz	2 kHz	2.5 kHz	3.15kHz	4 kHz	
HRA 20mm	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0
TSCS 6mm	-1	-1	-1	-2	-3	-3	-6	-6.5	-6.5	-6.5	-5	-4	-3	-6
TSCS 10mm	-1	-1	-1	-2	-3	-3	-6	-6.5	-6.5	-6.5	-5	-4	-3	-6
TSCS 14mm	0	0	0	0	-1	-2	-4	-4.5	-4.5	-4.5	-3	-2	-1	-6
Surface Dressing	0.5	0.5	0.5	-1	-2	-3	-2	1	2	2	1	0.5	0.5	0
Brushed Concrete	0	1	2	1	0	0	0	0	1	2	2	2	2	0
LDG Concrete	-4	-3	-2	-3	-4	-4	-4	-4	-3	-2	-2	-2	-2	0

Table 18: Vehicle Category 2 and 3

Road Surface	α													β
	250 Hz	315 Hz	400 Hz	500 Hz	630 Hz	800 Hz	1 kHz	1.25kHz	1.6 kHz	2 kHz	2.5 kHz	3.15kHz	4 kHz	
HRA 20mm	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	0
TSCS 6mm	-1	-1	-1	-2	-3	-4	-6	-6.5	-6.5	-6.5	-5	-4	-3	-4
TSCS 10mm	-1	-1	-1	-2	-3	-4	-6	-6.5	-6.5	-6.5	-5	-4	-3	-4
TSCS 14mm	0	0	-2	-3	-4	-3	-3	-4	-4.5	-4.5	-3	-2	-1	-4
Surface Dressing	0.5	0.5	0.5	-1	0	1	2	3	4	4	3	2	1	0
Brushed Concrete	0	1	2	1	0	1	1	1	2	3	3	3	3	0
LDG Concrete	-4	-3	-2	-3	-4	-3	-3	-3	-2	-1	-1	-1	-1	0

D.3 Temperature corrections

Coefficients for adjusting the rolling noise to account for the local air temperature are given in Table 19 for vehicles in category 1 and Table 20 for vehicles in categories 2 and 3. No correction is applied to vehicles in category 4. Porosity is correlated to the air void content of the surface layer and will be <5% for dense surfaces, 5-15% for semi-dense surfaces and >15% for open surface layers. Mean profile depth, or mean texture depth, is a measure of the smoothness of the surface layer and is typically around 1 mm for a TSCS.

Table 19: Coefficients for the temperature correction (K) for category 1 vehicles

	Porosity		
Mean Profile Depth	**<5%**	**5-15%**	**>15%**
<0.5 mm	0.04	0.06	0.08
0.5-1.5 mm	0.08	0.07	0.06
>1.5 mm	0.12	0.08	0.03

Table 20: Coefficients for the temperature correction (K) for category 2 and 3 vehicles

	Porosity		
Mean Profile Depth	**<5%**	**5-15%**	**>15%**
<0.5 mm	0.02	0.03	0.04
0.5-1.5 mm	0.04	0.035	0.03
>1.5 mm	0.06	0.04	0.015

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