Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire SK17 9JN

HEALTH & SAFETY LABORATORY

Hand-arm vibration emission of chainsaws – comparison with vibration exposure.

HSL/2004/13

Project Leader: Paul Pitts

Author(s): Paul Pitts BSc(hons) MIOA
Science Group: Human Factors Group

PRIVACY MARKING:

Available to anyone

HSL report approval:	Dr L Kenny
Date of issue:	July 2004
Job number:	JC4500006
Registry file:	NV/07/2002/21089
Electronic filename:	Report final V4-2.doc

RESTRICTED: COMMERCIAL

CONTENTS

EXECUTIVE SUMMARY

BACKGROUND

The manufacturer's declared vibration emission of a hand held power tool should be related to the vibration magnitude a_h. Unfortunately, for many tool types the relationship is poor and the vibration emission should not be used as a substitute for the in-use vibration magnitude. However, evidence from previous HSL studies suggests that for chain saws there is a usable relationship between emission and exposure.

Vibration exposure is highly dependent on exposure times. These will vary from job to job. To simplify the estimation procedure, it may be possible to take into account typical exposure times for a range of common activities.

At its simplest, the estimation procedure could use a simple multiplication factor for converting from vibration emission to a daily vibration exposure, with tables of constants provided for standard job types.

OBJECTIVES

The objective of this project was to establish whether it is feasible to produce simplified methods for estimating daily vibration exposures based on hand-arm vibration emission data provided by the saw manufacturers.

MAIN FINDINGS

1. All the manufacturer's published emission values were verified according to the definition in EN 12096.
2. For the in-forest measurements, the results from saws A, B and D were shown to be not statistically significantly different and saw E (the top-handled saw) and Saw C show as being statistically different from the other saws.
3. Ranking test showed that Saw E is the lowest-vibration saw and saw C is the highest, the others share equal ranking.
4. For all forest operations, except arboriculture and cross cutting, daily exposure consistently exceed the 2.5 $m/s^2A(8)$ exposure action value (EAV) defined in the EU Physical Agents (Vibration) Directive. In four cases the daily exposure limit value (ELV) of 5 $m/s^2A(8)$ is exceeded, these are all for the use of saw C.
5. There is some scope for simplification of exposure assessment, using nominal exposure times for job categories, rather than exact exposure times.
6. A table of multiplying values has been produced. This can be used for converting emission values to exposure estimates for the eight job categories seen in this study. Use of this table has been shown to result in errors in daily exposure estimates in the range from –34% to +46% when used with published emission data.
7. The use of the simplified exposure assessment methods, based on published ISO 7505 data, might usefully be used as a first stage vibration exposure assessment, to provide an indication of likely exposure, but should not be used as evidence that exposure is below an EAV or ELV, particularly where the predicted exposure value is close to the EAV or ELV.

1 INTRODUCTION

1.1 BACKGROUND

Manufacturers and suppliers of hand held power tools, such as chain saws, are required to provide information on hand-arm vibration emission. For chain saws the vibration emission values are derived from an ISO Standard test ISO 7505: 1986 “Forestry machinery - Chain saws - Measurement of hand-transmitted vibration”.

The users, and employers of users of handheld power tools need to assess the risk from vibration resulting from the use of those tools. A European Directive on Physical Agents (Vibration) published in July 2002 will result in the introduction of new UK legislation on hand-arm vibration exposure in 2005. The new legislation will place duties on employers based on an exposure action value for daily vibration exposure of 2.5 m/s²A(8) and an exposure limit value of 5 m/s²A(8).

The assessment of hand-arm vibration exposure is based on ISO standard ISO 5349-1:2000 “Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements”. This standard assesses hand-arm vibration exposure in terms of a daily exposure value, normalised to 8 hours, the *A(8)* value. This value is dependent on both vibration magnitude a_h and exposure time, *t*. For use of a single power tool:

$$A(8) = a_{hv}\sqrt{\frac{T}{\text{EightHours}}}$$

The vibration emission of a hand held power tool should be related to the vibration magnitude a_h. Unfortunately, for many tool types the relationship is poor and the vibration emission should not be used as a substitute for the in-use vibration magnitude. However, there is some evidence (Pitts et al 1990) that for chain saws there is a usable relationship between emission and exposure.

1.2 OBJECTIVES

The objective of this project was to establish whether it is feasible to produce simplified methods for estimating daily vibration exposures based on hand-arm vibration emission data provided by the saw manufacturers.

If there is a consistent relationship between the manufacturer’s declared emission values and the vibration magnitude on a tool handle when in real use, then it becomes possible to estimate vibration exposure from vibration emission data when the exposure time is known.

The declaration for chain saw vibration emission is based on a combination of results from three operating mode: idling, cutting and racing. An estimate of vibration exposure may be possible based solely upon this overall value. However, the results from the individual tests are available, and it may be necessary to use these individual components when estimating exposures.

Vibration exposure is highly dependent on exposure times. These will vary from job to job. To simplify the estimation procedure, it may be possible to take into account typical exposure times for a range of common job types, such as:

- General thinning
- Clear felling
- Brashing
- Crosscutting
- General woodland maintenance
- Arboriculture

At its simplest, the estimation procedure could use a simple multiplication factor for converting from vibration emission to a daily vibration exposure, with tables of constants provided for standard job types, for example:

$$A(8) = (a_e + K)C_T$$

Where a_e is the emission declaration level (with uncertainty K) and C_T is a value that accounts for:

- The difference between the emission data and the mean vibration magnitude for task T
- The typical daily exposure time for the task T. This can be considered for a full working day (assuming an 8 hour standard working day) and for a typical working day (allowing for shortened days due to weather or movement between sites).

With the values of C_T being tabulated for various common job types.

1.3 PROJECT PLAN

The project had the following structure:

Phase 1: Measure vibration emissions of 5 chainsaws, according to ISO 7505;

Phase 2: Evaluate vibration magnitude during normal operational elements using the 5 chainsaws from phase1;

Phase 3: By work-study of a cohort of FC foresters, determine the typical exposure times to the operational modes measured in Phase 2;

Phase 4; Review the data from Phase 1 – 3 to assess whether manufacturers vibration emission data can be used, along simple multiplication factors based on job titles, to provide reasonable estimates of likely daily vibration exposures.

Stihl and Husqvarna, sourced the five chainsaws for testing, and measured vibration emissions according to ISO 7505 (Phase1 – Results shown in Annex A).

The Forestry Research, Technical Development Branch (FR-TDB) carried out work-study evaluations (Phase 3 - Results summarised in Annex B) and identified and organised locations for vibration exposure measurements

The Health and Safety Laboratory (HSL) performed the hand-arm vibration exposure measurements (Phase 2) and has assessed the data to determine whether simple exposure estimates are viable.

2 STUDY METHODS

2.1 CHAINSAWS

Five chainsaws were used throughout these studies. Stihl and Husqvarna obtained the saws. They were chosen as being representative of saws of around 50cc capacity available on the market. The saws used throughout these tests are identified as saws A to E. Details of each saw are given in Annex A.

2.2 ISO 7505 TESTS

Vibration emission tests were performed by Husqvarna (saws A and B) and Stihl (saws C, D and E).

ISO 7505 tests require vibration to be measured at two locations on the saw: on the rear handle and on the top handle. Measurements are made with the saw in three operational modes: idling, cutting (full-load) and racing.

In idling mode the saw is held stationary in the position normally adopted between cuts (i.e. near horizontal). The cutting mode requires a cut to be taken through a specified test log while operating at a specified engine speed that is controlled using the feed force. The racing test is carried out at 133% of full-load speed, with the saw held as for the idling test.

Five repeats of each test are made; the averages of these are used as the declaration values.

2.3 HAND-ARM VIBRATION FOREST MEASUREMENTS

The original project plan was to perform a small number of “detailed” hand-arm vibration measurements, followed by a larger number of “simple” measurements using a hand-held vibration meter. During early “detailed” measurement, it became apparent that the “simple” measurements were impractical, due to rapid changes of hand-position, and the need to be able to select carefully sections of data for analysis.
The project plan was changed to allow more “detailed” measurement, with no “simple” measurements.

Measurements were made in the three UK forests listed in Table 1.

Table 1 Forests and tree types used for vibration measurements

Forests	Region	Tree type	Tree size (DBH in cm)	Ground type
Ae Forest	Dumfries	Sitka spruce	12 to 30	Upland peat forest
Alport Forest, Ladybower	Derbyshire	Sitka spruce	14 to 34	Sloped alluvial ground.
Cannock Chase	Staffordshire	Corsican pine	33 to 48	Heathland forest area sand stone
		Beech	36	

2.3.1 Data recording:

The data recording equipment for the detailed measurements is shown schematically in Figure 1.

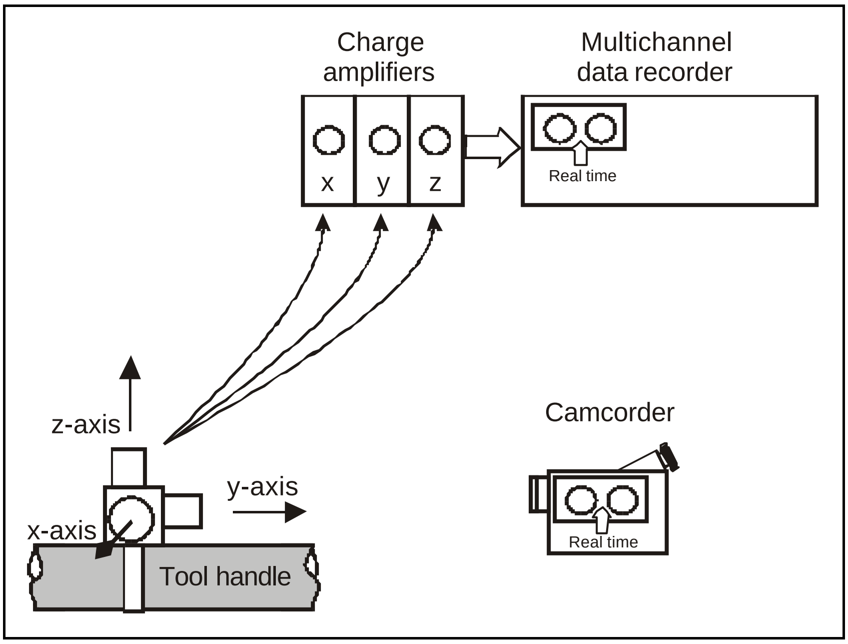


Figure 1 Diagram of data recording system

Three Brüel & Kjær type 4393 piezoelectric transducers are fitted to a small aluminium mounting-block, which is strapped firmly onto the tool handle using a non-ratchet type nylon cable tie. In the forest environment, three lengths of approximately 20m of high quality Endevco microdot cable were required between the transducers and the charge amplifiers, to allow a reasonable range of movement by the forester. A photograph showing the transducers fitted to a chainsaw is shown in Figure 2.

The vibration data were recorded on a TEAC RD135T 8 channel DAT recorder. During all measurements a camcorder recorded, as far as possible, the movements and activities of the forester.

Figure 2 Example of transducers fitted to rear handle

2.3.2 Analysis

The video recordings are used to identify suitable sections of recording for analysis. Periods where the forester's hand is in continuous contact with the machine handle being measured are used for analysis. In some cases, these sections may be as much as one minute; generally they are much less than this, due to the way the forester continuously changes grip and moves the chainsaw between hands while moving branches or moving between sections of felled trees.

Analysis of the vibration data recordings is carried out using a Brüel & Kjær Pulse analysis system (Figure 3). This system provides 1/3rd octave-band analysis from 1.6 Hz to 2.5 kHz and frequency weighted vibration magnitudes for three channels, and a frequency weighted time history based on the data from one axis.

Note: the measurement and analysis system is capable of handling 6 simultaneous channels of data (i.e. tri-axial data from two hand positions), however, it was impractical to deal with 6 cables running between the chainsaw and recording system in the forest environment.

The analyses are being performed based on three basic hand-positions:

- Rear (throttle) handle (right hand)
- Top handle (left hand on the top part of the wrap-around handle, used for vertical cuts)
- Side handle (left hand on the side part of the wrap-around handle, used for horizontal cuts)

The tasks being carried out are being analysed in categories that can easily be related to the categories used in the workstudy exercise, they are:

- Idling (both-hands and one-handed, supported and non-supported)
- Brashing

- De-buttressing – vertical cut
- De-butressing – horizontal cut
- Felling – vertical cut
- Felling – horizontal cut
- Snedding
- Cross-cutting
- General scrub clearance

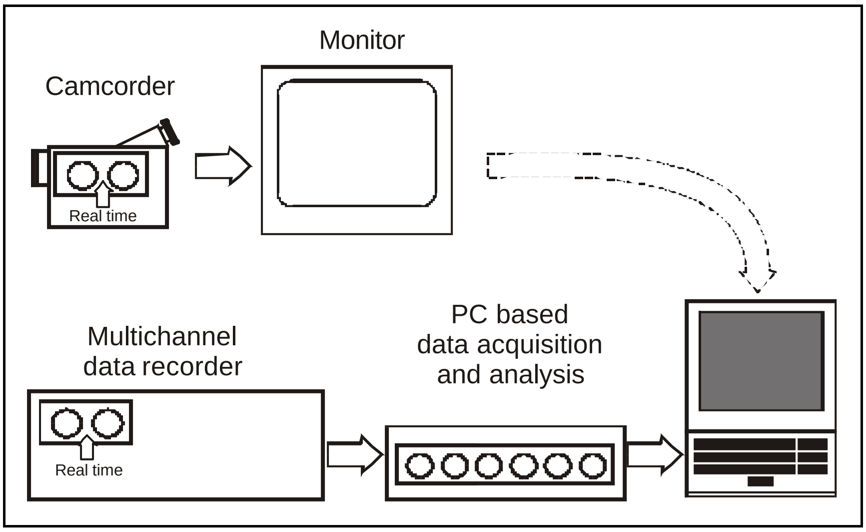


Figure 3 Diagram of data analysis system

2.4 EXPOSURE TIME STUDIES

2.4.1 Forest activities

The exposure time studies looked at the following forest activities:

First thinning	Tree size range 0.08 m^3 to 0.12 m^3 (softwoods)
Sub thin operation	Tree size range 0.15 m^3 to 0.25 m^3 (softwoods)
Clearfell operation	Tree size range > 0.25 m^3 (softwoods)
Brashing	Continuous brashing for subsequent mechanised harvesting (i.e. removal of the branches and small diameter stems attached to the tree below breast height diameter (softwoods).
Cross cutting	Continual cross cutting operation, the conversion of the tree stem into sections using the chainsaw (softwoods).
General clearance	Cutting of wood scrub or birch clearance operation. The species choice will not affect the method and technique used by the operator (softwoods and hardwoods).
Arboriculture	With the operator working in the tree: crown lifting, crown reduction or full pollarding (hardwoods).

2.4.2 Time-study chain-saw operating modes

Table 2 identifies the operating modes being assessed. These operating modes were chosen to provide some consistency with the hand-arm vibration magnitude measurements of phase 2.

Table 3 shows the number of studies for each forest operation type. The time studies were full-day studies, using activity sampling at time intervals of 0.5 minute.

Table 2 Chainsaw operating modes

Activity Code	Operating mode
A	Saw on ground, no contact
B	Two hands on saw, saw revving no load
B1	Two hands on saw, saw idling, on hip/thigh
B2	Two hands on saw, revving, horizontal, light load
B3	Two hands on saw, revving, vertical, light load
B4	Two hands on saw, horizontal, under load
B5	Two hands on saw, vertical, under load
B6	Two hands on saw, vertical, under load - Delimbing
C	One hand on front handle, saw on thigh, saw idling
C1	One hand on front handle, saw on stem, saw idling
C2	One hand on rear handle, saw on thigh, saw idling
C3	One hand on rear handle, saw on stem, saw idling
C4	One hand on rear handle, saw on ground, revving, no load
O	All other work not requiring handling of an operating chainsaw

Table 3 Number of studies per operation type

Operation type	Number of studies
First thinning	3
Subsequent thinning	3
Clearfell	3 in sitka spruce, 1 in pine
Brashing	1
Cross cutting	1
General maintenance/ Clearance	1
Arboriculture/ Tree surgery	2

3 RESULTS

3.1 ISO 7505 TESTS

Each of the five chainsaws used in this study was tested, before the forest measurements using the test procedure specified in ISO 7505. The results for each saw are summarised in Table 4.

Table 4 ISO 7505 emission test results (vibration total values in m/s²)

Saw	Emission mode results						Emission averages	
	Front (support) handle			Rear (throttle) handle				
	Idling	Cutting	Racing	Idling	Cutting	Racing	Front	Rear
Saw A	5.2	6.1	8.3	6.1	12.9	7.4	6.5	8.8
Saw B	7.0	6.1	5.3	6.5	4.7	7.0	6.1	6.1
Saw C	3.7	7.0	4.3	5.5	8.5	11.3	5.0	8.4
Saw D	4.0	5.8	5.0	6.6	6.4	3.1	4.9	5.4
Saw E	4.4	5.6	4.1	7.4	6.0	4.9	4.7	6.1

3.2 HAND-ARM VIBRATION FOREST MEASUREMENTS

Due to the highly variable use of hand-position and operating mode of chainsaws in forestry, the analysis of vibration values has needed to be broken up into periods where the hand is in contact with the handle (or part of the handle) to which the vibration transducers are attached. Saws A to D had measurements made at three locations:

- Throttle (rear) handle,
- Top of the support (front) handle,
- Side of the support (front) handle

For saw E, the top-handled saw, there was insufficient space on the handle to perform measurements actually on the throttle handle. However, it has been assumed that the support – top measurement position is also representative of the adjacent throttle hand position to which it is rigidly attached.

Over 900 individual hand arm vibration measurement analyses have been made on the five saws being operated in the three forest environments. For each measurement data in the format shown in Annex B.1 has been produced. The data from all measurements have been collated in a spreadsheet that allows data to be grouped and analysed by saw, measurement handle, operating mode. The analyses have all been performed using the overall total acceleration value (the “vector sum” acceleration), rather than individual axes.

Table 5 summarises the results from the hand-arm vibration measurements, arranged by saw, hand-position and forest operation type.

Table 5 Summary of average hand-arm vibration test results, in m/s^2

		Activity code									
		B	**B1**	**B2**	**B3**	**B4**	**B5**	**C**	**C1**	**C2**	**C3**
Saw	**Hand**	**Two hands on saw, saw revving no load**	**Two hands on saw, saw idling, on hip/thigh**	**Two hands on saw, revving, horizontal, light load**	**Two hands on saw, revving, vertical, light load**	**Two hands on saw, horizontal, under load**	**Two hands on saw, vertical, under load**	**One hand on front handle, saw on thigh, saw idling**	**One hand on front handle, saw on stem, saw idling**	**One hand on rear handle, saw on thigh, saw idling**	**One hand on rear handle, saw on stem, saw idling**
Saw A	Support - side		5.98	6.81		4.42	6.12	6.37			
	Support - top		4.48		5.68	5.83	4.88	4.34	4.12		
	Throttle		4.70		6.29	6.05	5.63				
Saw B	Support - side	2.29	4.22	6.39		4.06	5.82	4.50	4.54		
	Support - top		3.49		6.36	7.14	5.43	4.90	4.85		4.69
	Throttle	3.58	4.58		6.46	4.43	4.52				4.61
Saw C	Support - side		4.65			5.41					
	Support - top		4.03		6.99	6.82	6.79	5.27	5.01		
	Throttle		6.02		8.43	6.48	7.92				3.57
Saw D	Support - side		6.19	6.37		6.23	5.96	6.82			
	Support - top		3.76		6.73	8.42	5.96	3.51	3.72		
	Throttle		6.36		6.33	6.26	5.89			5.54	2.84
Saw E	Support - side		6.28	7.40		9.87	6.86	5.03			
	Support - top		2.97		3.66		4.10	4.04	4.77	2.74	3.75
	Throttle		*2.97*		*3.66*		*4.10*	*4.04*	*4.77*	*2.74*	*3.75*

* On the top handled saw, measurements at the support -top hand p osition are assumed to also represent the throttle hand position, since the two positions are very close to each other.

3.3 EXPOSURE TIME STUDIES

The results from the forestry time studies performed by FR-TDB are summarised in Table 6. The data given in Table 6 are extracted from FR-TDB report November 2003, however, it is assumed that the typical working day is 8 hours and the study times have been normalised to an 8-hour shift by FR-TDB. The same data is presented in Figure 4, showing the exposure times as a percentage of the time in contact with the saw.

Table 6 Daily exposure time-study results

Mode	Operation	First thin	Subs. Thin	Clear fell(SS)	Clear fell(pine)	Brashing	Cross cutting	Forest Cleaning	Arboriculture
	(mins.)								
A	Saw on ground, no contact	91.3	121.8	56.2	19.3	6.5	83.8	15.9	212.4
B	Two hands on saw, saw revving no load	20.7	4.1	9.2	22.7	8	1.6	1.4	5.3
B1	Two hands on saw, saw idling, on hip/thigh	3.5	1.4	1.5	2.1	7.3	2.1	49.1	0
B2	Two hands on saw, revving, horizontal, light load	0	0	0	6.2	0	1	0.5	0
B3	Two hands on saw, revving, vertical, light load	134.2	108.2	109.4	88	239.3	5.2	1	4.8
B4	Two hands on saw, horizontal, under load	13.2	18.9	27.1	19.9	0	0.5	138	0
B5	Two hands on saw, vertical, under load	37.6	45.9	62.9	58.4	0	26.9	44.2	35.8
B6	Two hands on saw, vertical, under load - Delimbing	0	0	0	0	0	0	0	0
C	One hand on front handle, saw on thigh, saw idling	32.6	30.9	29.2	47.4	13.1	33.1	69.3	0
C1	One hand on front handle, saw on stem, saw idling	1.6	5.2	22.6	16.5	0	0.5	0	0
C2	One hand on rear handle, saw on thigh, saw idling	0.3	0.3	0.4	0	0	0	14.4	1
C3	One hand on rear handle, saw on stem, saw idling	0	2.7	5.3	2.8	0	0	0	0
C4	One hand on rear handle, saw on ground, revving, no load	0.3	0.4	0.1	0	0	0	0	0
O	All other work not requiring handling of an operating chainsaw	144.7	140.2	156.1	196.7	205.8	325.3	146.2	220.7
	Total saw in hand (mins)	244	218	267.7	264	267.7	70.9	317.9	46.9
	Total working day(mins)	480	480	480	480	480	480	480	480
	Total saw in hand (hh:mm:ss)	4:04	3:38	4:27	4:24	4:27	1:10	5:17	0:46
	Total working day (hh:mm:ss)	8:00	8:00	8:00	8:00	8:00	8:00	8:00	8:00
	Average total study time (hh:mm:ss)	8:47	9:27	5:45	5:48	5:30	7:43	8:18	8:15

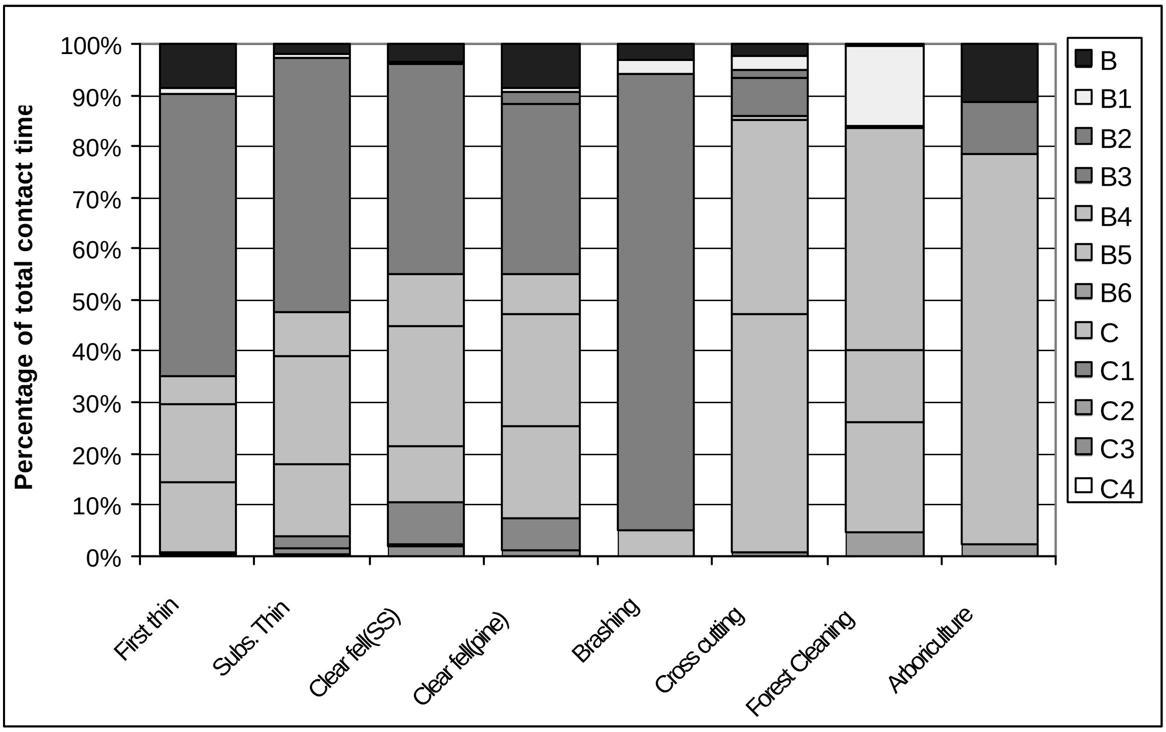


Figure 4 Distribution of exposure times for the forest activities

3.4 ESTIMATIONS OF DAILY VIBRATION EXPOSURES

3.4.1 Methods of assessment

Vibration exposure may be evaluated in a number of different ways, to compare the alternative sources of vibration magnitude and exposure time information, daily vibration exposures have been calculated based on:

1. **In-forest measured vibration data and time-study data**. This method provides the best estimate of daily vibration exposure, and is used as the reference against which the other methods are compared.
2. **Measured vibration emission mode data and time-study data**. This method uses the most detailed emission data from ISO 7505 tests on the actual saws used in this study (i.e. idling, cutting and racing data), and of the exposure estimates based on emission data, might be expected to give the best results.
3. **Measured vibration emission averaged data and time-study data.** This method uses the averaged emission test data, based on ISO 7505 tests on the actual saws used in this study. (i.e. a single value is used to represent all modes of chainsaw use).
4. **Published vibration emission averaged data and time-study data.** Most chain saws users will only have access to published emission data, usually in the form of averaged data (i.e. for each model, an average of idling, cutting and racing data). This method represents the best estimation method available to most chainsaw users.
5. **In-forest measured vibration data and nominal exposure time data.** This method has been included to illustrate that the accurate evaluation of exposure time is less important that the accurate evaluation of vibration magnitude.

3.4.2 Estimation based on measured vibration and time-study data

To assess likely daily vibration exposures from the hand-arm vibration analyses and the time-study analyses the appropriate vibration values need to be assigned to the exposure categories used in the time-study. While the exposure time categories were designed to relate to the categories used in the vibration analyses, the relationships are not in all cases straightforward.

The vibration analyses produced a range of descriptions for the operations, depending on which hand-position was being assessed, and the operation type. Table 7 shows the vibration analysis categories, and how they were mapped onto the time-study modes.

Table 7 Mapping of vibration measurement categories to time-study chain saw operating modes

Vibration description	Time-study mode / description	
Racing	B	Two hands on saw, saw revving no load
Idling - away from body - Held with both hands	B1	Two hands on saw, saw idling, on hip/thigh
Idling - Both hands - on knee, on its side	B1	Two hands on saw, saw idling, on hip/thigh
Idling - Both hands - on trunk, on its side	B1	Two hands on saw, saw idling, on hip/thigh
Snedding - horizontal	B2	Two hands on saw, revving, horizontal, light load
Brashing	B3	Two hands on saw, revving, vertical, light load
Snedding	B3	Two hands on saw, revving, vertical, light load
Snedding - vertical	B3	Two hands on saw, revving, vertical, light load
Cross cutting-Horizontal	B4	Two hands on saw, horizontal, under load
Felling	B4	Two hands on saw, horizontal, under load
Felling – Horizontal cut	B4	Two hands on saw, horizontal, under load
Cross cutting	B5	Two hands on saw, vertical, under load
Cross cutting-Vertical	B5	Two hands on saw, vertical, under load
Felling - Vertical cut	B5	Two hands on saw, vertical, under load
Idling - Support handle - on knee	C	One hand on front handle, saw on thigh, saw idling
Idling - Support handle only	C	One hand on front handle, saw on thigh, saw idling
Idling - Idling on trunk held only on support	C1	One hand on front handle, saw on stem, saw idling
Idling - Support handle - on trunk, on its side	C1	One hand on front handle, saw on stem, saw idling
Idling - Throttle handle on knee	C2	One hand on rear handle, saw on thigh, saw idling
Idling - on trunk - Held with rear hand only - saw horizontal	C3	One hand on rear handle, saw on stem, saw idling
Idling - on trunk - Held with rear hand only - saw vertical	C3	One hand on rear handle, saw on stem, saw idling
Idling - Throttle handle on trunk	C3	One hand on rear handle, saw on stem, saw idling
Idling - Throttle handle pointing down	C3	One hand on rear handle, saw on stem, saw idling

In addition to the mapping shown in Table 7, some substitutions need to be made for before estimates of daily vibration exposure can be made:

1. For the Saw E, the top-handled saw, there is no space available on the throttle handle to attach transducers, however, the top-support handle is very close to the throttle handle and rigidly attached to the same support, therefore vibration measurements from the top of the support handle are assumed to apply also to the throttle hand position.
2. For the vibration measurements on the throttle (rear) handle, there is no distinction between horizontal and vertical saw operation. Although this mode is mapped to activity B3 (two hands on saw, revving, vertical, light load) it also applies to activity B2 (two hands on saw, revving, horizontal, light load).
3. No specific vibration data was collected for activity B6 (vertical de-limbing), which is assumed to be the same as activity B3 (two hands on saw, revving, vertical, light load).
4. Little data was collected for "racing" (activities B and C4), in practice this operation takes place as the saw is warmed up, or is seen briefly between other operations, such as snedding or brashing. Since the "racing" generally involves revving the saw through a range of speeds, similar to light cutting activities, then data from vertical light load (B3) has been used where specific "racing" data is not available.
5. Where data for C2 and C3 (rear hand only idling activities) are not available then rear hand data from B1 (Two hands on saw, saw idling, on hip/thigh) is used.

With the exception of the substitutions relating to the top-handle saw, these substitutions all relate to activities for which the assessed exposure times are small. They are not therefore likely to have any significant effect on the assessment of daily vibration exposures.

In Table 8 the vibration exposure times evaluated by FR-TDB (i.e. the data from Table 5) and the in-forest vibration measurements from Table 5 have been used to calculate the vibration exposures associated with the 8 work activities. These values are assumed to be the best estimates of daily vibration exposures; they are the values against which all simplifications to the methods of estimating vibration exposures will be compared.

Table 8 Daily exposure estimates for activities based on in-forest measured vibration values and time-study data (m/s²A(8)).

Activity	Saw	Rear hand	Front hand	Highest hand*
First thin	Saw A	4.1	3.8	4.1
First thin	Saw B	3.8	4.2	4.2
First thin	Saw C	5.4	4.7	**5.4**
First thin	Saw D	4.1	4.4	4.4
Subs. Thin	Saw A	3.7	3.5	3.7
Subs. Thin	Saw B	3.5	3.8	3.8
Subs. Thin	Saw C	5.0	4.4	5.0
Subs. Thin	Saw D	3.8	4.1	4.1
Clear fell(SS)	Saw A	4.0	3.8	4.0
Clear fell(SS)	Saw B	3.7	4.2	4.2
Clear fell(SS)	Saw C	5.4	4.8	**5.4**
Clear fell(SS)	Saw D	4.1	4.4	4.4
Clear fell(pine)	Saw A	3.9	3.8	3.9
Clear fell(pine)	Saw B	3.5	4.2	4.2
Clear fell(pine)	Saw C	5.2	4.7	**5.2**
Clear fell(pine)	Saw D	4.0	4.3	4.3
Brashing	Saw A	4.6	4.2	4.6
Brashing	Saw B	4.6	4.7	4.7
Brashing	Saw C	6.1	5.1	**6.1**
Brashing	Saw D	4.6	4.9	4.9
Cross cutting	Saw A	1.6	1.8	*1.8*
Cross cutting	Saw B	1.3	2.0	*2.0*
Cross cutting	Saw C	2.2	2.3	*2.3*
Cross cutting	Saw D	1.7	1.9	*1.9*
Forest Cleaning	Saw A	4.1	3.6	4.1
Forest Cleaning	Saw B	3.2	3.5	3.5
Forest Cleaning	Saw C	4.8	4.3	4.8
Forest Cleaning	Saw D	4.4	4.2	4.4
Arboriculture	Saw A	1.8	1.6	*1.8*
Arboriculture	Saw B	1.5	1.7	*1.7*
Arboriculture	Saw C	2.5	2.1	2.5
Arboriculture	Saw D	1.9	1.9	*1.9*
Arboriculture	Saw E	1.2	1.2	*1.2*

* Daily exposure above 5m/s²A(8) are shown in bold, daily exposures below 2.5m/s² are shown in italics

3.4.3 Estimation based on vibration emission and time-study data

Vibration exposure might be estimated using vibration data from the three ISO 7505 vibration emission test modes. First, each exposure category has to be mapped onto one of the ISO 7505 test modes. The mapping shown in Table 9 has been used here.

Table 9 Mapping of time-study modes to emission test modes

Time-study mode, Description		Equivalent Emission mode
B	Two hands on saw, saw revving no load	Cutting*
B1	Two hands on saw, saw idling, on hip/thigh	Idling
B2	Two hands on saw, revving, horizontal, light load	Cutting
B3	Two hands on saw, revving, vertical, light load	Cutting
B4	Two hands on saw, horizontal, under load	Cutting
B5	Two hands on saw, vertical, under load	Cutting
B6	Two hands on saw, vertical, under load - Delimbing	Cutting
C	One hand on front handle, saw on thigh, saw idling	Idling
C1	One hand on front handle, saw on stem, saw idling	Idling
C2	One hand on rear handle, saw on thigh, saw idling	Idling
C3	One hand on rear handle, saw on stem, saw idling	Idling
C4	One hand on rear handle, saw on ground, revving, no load	Cutting*

* Although, in name, these modes appear to be closely related to "racing", the variation in speed of the saw during these modes is probably better related to cutting activities. Since these modes account for small proportions of the day's exposure, the effect of changing the mapping is small.

The estimates of daily vibration exposure in Table 10 have been calculated using the mapping in Table 9, and the exposure times from Table 6.

Table 10 Daily exposure estimates for activities based on ISO 7505 vibration emission test mode values and time-study data (m/s²A(8)).

Activity	Saw	Rear hand	Front hand	Highest hand*
First thin	Saw A	8.5	4.3	**8.5**
First thin	Saw B	3.1	4.4	4.4
First thin	Saw C	5.6	4.7	**5.6**
First thin	Saw D	4.2	4.0	4.2
Subs. Thin	Saw A	7.9	4.0	**7.9**
Subs. Thin	Saw B	2.9	4.2	4.2
Subs. Thin	Saw C	5.2	4.4	**5.2**
Subs. Thin	Saw D	3.9	3.7	3.9
Clear fell(SS)	Saw A	8.5	4.4	**8.5**
Clear fell(SS)	Saw B	3.2	4.6	4.6
Clear fell(SS)	Saw C	5.6	4.8	**5.6**
Clear fell(SS)	Saw D	4.3	4.0	4.3
Clear fell(pine)	Saw A	8.2	4.3	**8.2**
Clear fell(pine)	Saw B	3.1	4.7	4.7
Clear fell(pine)	Saw C	5.4	4.7	**5.4**
Clear fell(pine)	Saw D	4.1	4.0	4.1
Brashing	Saw A	9.3	4.5	**9.3**
Brashing	Saw B	3.5	4.6	4.6
Brashing	Saw C	6.1	5.1	**6.1**
Brashing	Saw D	4.7	4.2	4.7
Cross cutting	Saw A	3.5	2.2	3.5
Cross cutting	Saw B	1.3	2.5	2.5
Cross cutting	Saw C	2.3	2.1	*2.3*
Cross cutting	Saw D	1.8	1.9	*1.9*
Forest Cleaning	Saw A	8.3	4.6	**8.3**
Forest Cleaning	Saw B	3.8	5.1	**5.1**
Forest Cleaning	Saw C	5.6	4.7	**5.6**
Forest Cleaning	Saw D	4.6	4.1	4.6
Arboriculture	Saw A	4.0	1.9	4.0
Arboriculture	Saw B	1.5	1.9	*1.9*
Arboriculture	Saw C	2.6	2.2	2.6
Arboriculture	Saw D	2.0	1.8	*2.0*
Arboriculture	Saw E	1.9	1.7	*1.9*

* Daily exposure above 5m/s²A(8) are shown in bold, daily exposures below 2.5m/s² are shown in italics

3.4.4 Estimation based on vibration averaged emission data and time-study data

Manufacturers usually present ISO 7505 data as either one or two values: representing the combined emission value for the highest hand or both hands. The combination of emission values being produced by:

$$a_{emission} = \tfrac{1}{3} a_{idling} + \tfrac{1}{3} a_{cutting} + \tfrac{1}{3} a_{racing}$$

The averaged emission values have been calculated from the emission test results for each mode and are shown in Table 11.

Table 11 Averaged emission values (m/s²)

Saw	Support - top Front	Throttle Rear	Highest Hand Value
Saw A	6.5	8.8	8.8
Saw B	6.1	6.1	6.1
Saw C	5.0	8.4	8.4
Saw D	4.9	5.4	5.4
Saw E	4.7	6.1	6.1

The estimations of daily vibration exposures in Table 12 have been calculated using the single emission values for each hand to represent any type vibration exposure (idling, revving, cutting, etc.).

Table 12 Daily vibration exposure based on single value emission test data and time-study data (m/s²A(8)).

Activity	Saw	Rear hand	Front hand	Highest hand*
First thin	Saw A	5.8	4.7	**5.8**
First thin	Saw B	4.0	4.4	4.4
First thin	Saw C	5.6	3.6	**5.6**
First thin	Saw D	3.5	3.5	3.5
Subs. Thin	Saw A	5.4	4.4	**5.4**
Subs. Thin	Saw B	3.7	4.1	4.1
Subs. Thin	Saw C	5.2	3.3	**5.2**
Subs. Thin	Saw D	3.3	3.3	3.3
Clear fell(SS)	Saw A	5.9	4.8	**5.9**
Clear fell(SS)	Saw B	4.1	4.5	4.5
Clear fell(SS)	Saw C	5.7	3.7	**5.7**
Clear fell(SS)	Saw D	3.6	3.6	3.6
Clear fell(pine)	Saw A	5.7	4.8	**5.7**
Clear fell(pine)	Saw B	3.9	4.5	4.5
Clear fell(pine)	Saw C	5.4	3.7	**5.4**
Clear fell(pine)	Saw D	3.5	3.6	3.6
Brashing	Saw A	6.4	4.9	**6.4**
Brashing	Saw B	4.4	4.6	4.6
Brashing	Saw C	6.1	3.7	**6.1**
Brashing	Saw D	3.9	3.7	3.9
Cross cutting	Saw A	2.5	2.5	2.5
Cross cutting	Saw B	1.7	2.4	*2.4*
Cross cutting	Saw C	2.4	1.9	*2.4*
Cross cutting	Saw D	1.5	1.9	*1.9*
Forest Cleaning	Saw A	6.3	5.2	**6.3**
Forest Cleaning	Saw B	4.4	4.9	4.9
Forest Cleaning	Saw C	6.1	4.0	**6.1**
Forest Cleaning	Saw D	3.9	3.9	3.9
Arboriculture	Saw A	2.8	2.0	2.8
Arboriculture	Saw B	1.9	1.9	*1.9*
Arboriculture	Saw C	2.6	1.5	2.6
Arboriculture	Saw D	1.7	1.5	*1.7*
Arboriculture	Saw E	1.9	1.5	*1.9*

* Daily exposure above 5m/s²A(8) are shown in bold, daily exposures below 2.5m/s² are shown in italics

3.4.5 Estimation based on published average emission data and time-study data

The values of vibration emission used for Tables 10 and 12 have been based on the measurements of vibration emission performed on the actual saws used in this project. Not all users will have the luxury of emission tests performed on the actual machines they are using, and will therefore need to use ISO 7505 information published by the manufacturers in the instruction manuals (referred to in this report as the "published emission data").

For the saw types tested the manufacturer's published emission information was obtained, see Table 13. The published emission values have been used, with the nominal exposure times, to produce the daily vibration exposure estimates in Table 14.

Table 13 Manufacturer's published emission test data (m/s^2)

Saw	Single value	Support - top Front	Throttle Rear	Highest hand value
Saw A		6.9	5.9	6.9
Saw B		4.2	3.9	4.2
Saw C	8.8			8.8
Saw D		6.9	7.6	7.6
Saw E		3.4	5.3	5.3

Table 14 Daily vibration exposure based on published emission test data and time-study data (m/s²A(8))

Activity	Saw	Rear hand	Front hand	Highest hand*
First thin	Saw A	3.9	4.9	4.9
First thin	Saw B	2.6	3.0	3.0
First thin	Saw C	5.8	6.3	**6.3**
First thin	Saw D	5.0	4.9	**5.0**
Subs. Thin	Saw A	3.6	4.6	4.6
Subs. Thin	Saw B	2.4	2.8	2.8
Subs. Thin	Saw C	5.4	5.9	**5.9**
Subs. Thin	Saw D	4.7	4.6	4.7
Clear fell(SS)	Saw A	4.0	5.1	**5.1**
Clear fell(SS)	Saw B	2.6	3.1	3.1
Clear fell(SS)	Saw C	5.9	6.5	**6.5**
Clear fell(SS)	Saw D	5.1	5.1	**5.1**
Clear fell(pine)	Saw A	3.8	5.1	**5.1**
Clear fell(pine)	Saw B	2.5	3.1	3.1
Clear fell(pine)	Saw C	5.7	6.5	**6.5**
Clear fell(pine)	Saw D	4.9	5.1	**5.1**
Brashing	Saw A	4.3	5.2	**5.2**
Brashing	Saw B	2.8	3.1	3.1
Brashing	Saw C	6.4	6.6	**6.6**
Brashing	Saw D	5.5	5.2	**5.5**
Cross cutting	Saw A	1.6	2.7	2.7
Cross cutting	Saw B	1.1	1.6	*1.6*
Cross cutting	Saw C	2.5	3.4	3.4
Cross cutting	Saw D	2.1	2.7	2.7
Forest Cleaning	Saw A	4.2	5.5	**5.5**
Forest Cleaning	Saw B	2.8	3.3	3.3
Forest Cleaning	Saw C	6.3	7.0	**7.0**
Forest Cleaning	Saw D	5.5	5.5	**5.5**
Arboriculture	Saw A	1.8	2.1	*2.1*
Arboriculture	Saw B	1.2	1.3	*1.3*
Arboriculture	Saw C	2.8	2.7	2.8
Arboriculture	Saw D	2.4	2.1	*2.4*
Arboriculture	Saw E	1.7	1.1	*1.7*

* Daily exposure above 5m/s²A(8) are shown in bold,
daily exposures below 2.5m/s² are shown in italics

3.4.6 Estimation based on measured vibration data and nominal exposure times

The calculation of daily vibration exposure is influenced less by the uncertainty of exposure time than the uncertainty of vibration magnitude. For this reason, it is possible to use cruder assessments of exposure time and still produce reasonably reliable assessments of daily vibration exposure. To illustrate this point, the estimate of daily vibration exposure are repeated here using the measured vibration magnitudes and nominal exposure times.

To obtain the nominal exposure times, the exposure times from the time-studies Table 6, are rounded to a nearest nominal time selected from Table 15. The equivalent rounded (or nominal) exposure times are given in Table 16. These rounded exposure times are then used with the in-forest vibration magnitudes values to provide a further set of daily exposures estimate, see Table 17.

Table 15 Nominal exposure time categories

5 mins	10 mins	20 mins	30 mins	45 mins	1 hour	1½ hours	2 hours	3 hours	4 hours	6 hours	8 hours	12 hours

Table 16 Nominal daily exposure times

Mode	Operation	First thin	Subs. Thin	Clear fell(SS)	Clear fell(pine)	Brashing	Cross cutting	Forest Cleaning	Arboriculture
		Nominal daily exposure time (hh:mm)							
B	Two hands on saw, saw revving no load	0:20	0:05	0:10	0:20	0:10	-	-	0:05
B1	Two hands on saw, saw idling, on hip/thigh	0:05	-	-	-	0:10	-	0:45	-
B2	Two hands on saw, revving, horizontal, light load	-	-	-	0:05	-	-	-	-
B3	Two hands on saw, revving, vertical, light load	2:00	2:00	2:00	1:30	4:00	0:05	-	0:05
B4	Two hands on saw, horizontal, under load	0:10	0:20	0:30	0:20	-	-	2:00	-
B5	Two hands on saw, vertical, under load	0:45	0:45	1:00	1:00	-	0:30	0:45	0:30
B6	Two hands on saw, vertical, under load - Delimbing	-	-	-	-	-	-	-	-
C	One hand on front handle, saw on thigh, saw idling	0:30	0:30	0:30	0:45	0:10	0:30	1:00	-
C1	One hand on front handle, saw on stem, saw idling	-	0:05	0:20	0:20	-	-	-	-
C2	One hand on rear handle, saw on thigh, saw idling	-	-	-	-	-	-	0:10	-
C3	One hand on rear handle, saw on stem, saw idling	-	-	0:05	-	-	-	-	-
C4	One hand on rear handle, saw on ground, revving, no load	-	-	-	-	-	-	-	-

Table 17 Daily vibration exposure based on in-forest measured vibration data and nominal exposure times (m/s²A(8))

Activity	Saw	Rear hand	Front hand	Highest hand*
First thin	Saw A	3.9	3.7	3.9
First thin	Saw B	3.7	4.1	4.1
First thin	Saw C	5.3	4.6	**5.3**
First thin	Saw D	4.0	4.3	4.3
Subs. Thin	Saw A	3.8	3.6	3.8
Subs. Thin	Saw B	3.6	4.0	4.0
Subs. Thin	Saw C	5.1	4.5	**5.1**
Subs. Thin	Saw D	3.9	4.2	4.2
Clear fell(SS)	Saw A	4.1	3.8	4.1
Clear fell(SS)	Saw B	3.8	4.3	4.3
Clear fell(SS)	Saw C	5.5	4.9	**5.5**
Clear fell(SS)	Saw D	4.2	4.5	4.5
Clear fell(pine)	Saw A	3.8	3.8	3.8
Clear fell(pine)	Saw B	3.5	4.2	4.2
Clear fell(pine)	Saw C	5.1	4.7	**5.1**
Clear fell(pine)	Saw D	3.9	4.3	4.3
Brashing	Saw A	4.6	4.2	4.6
Brashing	Saw B	4.6	4.7	4.7
Brashing	Saw C	6.1	5.1	**6.1**
Brashing	Saw D	4.7	4.9	4.9
Cross cutting	Saw A	1.5	1.7	*1.7*
Cross cutting	Saw B	1.3	1.9	*1.9*
Cross cutting	Saw C	2.2	2.3	*2.3*
Cross cutting	Saw D	1.6	1.9	*1.9*
Forest Cleaning	Saw A	3.8	3.4	3.8
Forest Cleaning	Saw B	3.0	3.3	3.3
Forest Cleaning	Saw C	4.5	4.1	4.5
Forest Cleaning	Saw D	4.2	4.0	4.2
Arboriculture	Saw A	1.7	1.5	*1.7*
Arboriculture	Saw B	1.4	1.6	*1.6*
Arboriculture	Saw C	2.3	2.0	*2.3*
Arboriculture	Saw D	1.7	1.8	*1.8*
Arboriculture	Saw E	1.2	1.2	*1.2*

* Daily exposure above 5m/s²A(8) are shown in bold,
daily exposures below 2.5m/s² are shown in italics

3.5 DIFFERENCES IN DAILY EXPOSURE ESTIMATES

Tables 8, 10, 12, 14 and 17 show the results from the five alternative methods of arriving at estimates of daily vibration exposure values. To allow easy comparison of the methods, Table 18 summarises the results from the five methods by reproducing the highest axis data values from Tables 8, 10, 12, 14 and 17.

The differences between the results from the five methods are presented in Table 19 as percentage differences from the results given by the detailed evaluation method (i.e. the data from Table 8). The values in Table 19 are given by:

$$e_{simplifiedMethod} = \left(\frac{a_{simplifiedMethod} - a_{detailedMethod}}{a_{detailedMethod}} \right) x100$$

It is useful to view these percentage differences sorted by saw type, Table 20; this presentation of the data highlights the problems with predictions based on emission test data from saw A.

Values at or near to 0% in Tables 19 and 20 represent good agreement between the measured vibration exposures and the estimated values based on vibration emission data. Negative values indicate underestimation (and the use of these values in any risk assessment is likely to result in under-protection of the worker); positive values indicate overestimates of daily exposure (and would lead to over-protection).

Saw A appears to have given higher than expected ISO 7505 emission data for the cutting test on the rear hand position (see Table 3, saw A gives 12.9 m/s² where other machines give between 4.7 and 8.5m/s² for the same test), this data distorts subsequent exposure evaluations, and is much higher than the manufacturer's published data for the same machine type.

For an estimation method to be useful, it should not produce excessively large positive differences (i.e. method that potentially could lead to over protection by a large amount), and should only produce small negative differences (i.e. is unlikely to underprotect, but where it does it is by a small amount). The best indicator of the overall quality of each estimate type is the r.m.s value. The r.m.s. value is used to recognise the fact that both positive and negative differences are undesirable (a simple average value is not useful, since positive differences are cancelled out by negative differences). Table 20 also shows minimum, maximum and r.m.s values for the difference values. Maximum, minimum and r.m.s difference data are also calculated with the difference data from saw A excluded.

Table 18 Comparison of highest handle daily vibration exposure estimates (m/s²A(8))

	Vibration data:	Measured	Emission mode	Emission averaged	Published emission	Measured
	Exposure time data:	----------	Time-studies	----------		Nominal
Activity	**Saw**	***Table 8***	***Table 10***	***Table 12***	***Table 14***	***Table 17***
First thin	Saw A	4.1	**8.5**	**5.8**	4.9	3.9
First thin	Saw B	4.2	4.4	4.4	3.0	4.1
First thin	Saw C	**5.4**	**5.6**	**5.6**	**6.3**	**5.3**
First thin	Saw D	4.4	4.2	3.5	**5.0**	4.3
Subs. Thin	Saw A	3.7	**7.9**	**5.4**	4.6	3.8
Subs. Thin	Saw B	3.8	4.2	4.1	2.8	4.0
Subs. Thin	Saw C	5.0	**5.2**	**5.2**	**5.9**	**5.1**
Subs. Thin	Saw D	4.1	3.9	3.3	4.7	4.2
Clear fell(SS)	Saw A	4.0	**8.5**	**5.9**	**5.1**	4.1
Clear fell(SS)	Saw B	4.2	4.6	4.5	3.1	4.3
Clear fell(SS)	Saw C	**5.4**	**5.6**	**5.7**	**6.5**	**5.5**
Clear fell(SS)	Saw D	4.4	4.3	3.6	**5.1**	4.5
Clear fell(pine)	Saw A	3.9	**8.2**	**5.7**	**5.1**	3.8
Clear fell(pine)	Saw B	4.2	4.7	4.5	3.1	4.2
Clear fell(pine)	Saw C	**5.2**	**5.4**	**5.4**	**6.5**	**5.1**
Clear fell(pine)	Saw D	4.3	4.1	3.6	**5.1**	4.3
Brashing	Saw A	4.6	**9.3**	**6.4**	**5.2**	4.6
Brashing	Saw B	4.7	4.6	4.6	3.1	4.7
Brashing	Saw C	**6.1**	**6.1**	**6.1**	**6.6**	**6.1**
Brashing	Saw D	4.9	4.7	3.9	**5.5**	4.9
Cross cutting	Saw A	*1.8*	3.5	2.5	2.7	*1.7*
Cross cutting	Saw B	*2.0*	2.5	*2.4*	*1.6*	*1.9*
Cross cutting	Saw C	*2.3*	*2.3*	*2.4*	3.4	*2.3*
Cross cutting	Saw D	*1.9*	*1.9*	*1.9*	2.7	*1.9*
Forest Cleaning	Saw A	4.1	**8.3**	**6.3**	**5.5**	3.8
Forest Cleaning	Saw B	3.5	**5.1**	4.9	3.3	3.3
Forest Cleaning	Saw C	4.8	**5.6**	**6.1**	**7.0**	4.5
Forest Cleaning	Saw D	4.4	4.6	3.9	**5.5**	4.2
Arboriculture	Saw A	*1.8*	4.0	2.8	*2.1*	*1.7*
Arboriculture	Saw B	*1.7*	*1.9*	*1.9*	*1.3*	*1.6*
Arboriculture	Saw C	2.5	2.6	2.6	2.8	*2.3*
Arboriculture	Saw D	*1.9*	*2.0*	*1.7*	*2.4*	*1.8*
Arboriculture	Saw E	*1.2*	*1.9*	*1.9*	*1.7*	*1.2*

Note: Daily exposure above 5m/s²A(8) are shown in bold, daily exposures below 2.5m/s² are shown in italics

Table 19 Comparison of highest handle daily vibration exposure estimates as percentage differences from the detailed method (%)

	Vibration data:	Emission mode	Emission averaged	Published emission	Measured
	Exposure time data:	---------- Time-studies		----------	Nominal
Activity	**Saw**	***Table 10***	***Table 12***	***Table 14***	***Table 17***
First thin	Saw A	109	43	21	-3
First thin	Saw B	6	4	-29	-3
First thin	Saw C	3	3	16	-3
First thin	Saw D	-4	-20	14	-3
Subs. Thin	Saw A	111	45	23	3
Subs. Thin	Saw B	9	7	-27	3
Subs. Thin	Saw C	5	5	18	3
Subs. Thin	Saw D	-3	-19	15	3
Clear fell(SS)	Saw A	111	46	26	3
Clear fell(SS)	Saw B	11	9	-26	2
Clear fell(SS)	Saw C	5	6	21	2
Clear fell(SS)	Saw D	-3	-17	15	3
Clear fell(pine)	Saw A	113	47	31	-1
Clear fell(pine)	Saw B	12	9	-26	0
Clear fell(pine)	Saw C	6	6	26	-1
Clear fell(pine)	Saw D	-4	-16	18	0
Brashing	Saw A	104	41	13	1
Brashing	Saw B	-1	-2	-33	0
Brashing	Saw C	1	1	8	1
Brashing	Saw D	-5	-20	13	1
Cross cutting	Saw A	93	38	46	-5
Cross cutting	Saw B	25	17	-20	-4
Cross cutting	Saw C	1	2	47	-2
Cross cutting	Saw D	0	-1	38	-3
Forest Cleaning	Saw A	104	56	35	-6
Forest Cleaning	Saw B	46	38	-5	-6
Forest Cleaning	Saw C	18	26	46	-6
Forest Cleaning	Saw D	4	-12	23	-6
Arboriculture	Saw A	122	53	18	-7
Arboriculture	Saw B	8	9	-26	-6
Arboriculture	Saw C	6	5	10	-7
Arboriculture	Saw D	5	-12	25	-6
Arboriculture	Saw E	51	53	33	-7

Table 20 Comparison of highest handle daily vibration exposure estimates as percentage differences from the detailed method, sorted by saw (%)

	Vibration data:	Emission mode	Emission averaged	Published emission	Measurec
	Exposure time data:	----------	Time-studies	----------	Nominal
Saw	**Rear hand**	***Table 10***	***Table 12***	***Table 14***	***Table 17***
Saw A	First thin	109	43	21	-3
Saw A	Subs. Thin	111	45	23	3
Saw A	Clear fell(SS)	111	46	26	3
Saw A	Clear fell(pine)	113	47	31	-1
Saw A	Brashing	104	41	13	1
Saw A	Cross cutting	93	38	46	-5
Saw A	Forest Cleaning	104	56	35	-6
Saw A	Arboriculture	122	53	18	-7
Saw B	First thin	6	4	-29	-3
Saw B	Subs. Thin	9	7	-27	3
Saw B	Clear fell(SS)	11	9	-26	2
Saw B	Clear fell(pine)	12	9	-26	0
Saw B	Brashing	-1	-2	-33	0
Saw B	Cross cutting	25	17	-20	-4
Saw B	Forest Cleaning	46	38	-5	-6
Saw B	Arboriculture	8	9	-26	-6
Saw C	First thin	3	3	16	-3
Saw C	Subs. Thin	5	5	18	3
Saw C	Clear fell(SS)	5	6	21	2
Saw C	Clear fell(pine)	6	6	26	-1
Saw C	Brashing	1	1	8	1
Saw C	Cross cutting	1	2	47	-2
Saw C	Forest Cleaning	18	26	46	-6
Saw C	Arboriculture	6	5	10	-7
Saw D	First thin	-4	-20	14	-3
Saw D	Subs. Thin	-3	-19	15	3
Saw D	Clear fell(SS)	-3	-17	15	3
Saw D	Clear fell(pine)	-4	-16	18	0
Saw D	Brashing	-5	-20	13	1
Saw D	Cross cutting	0	-1	38	-3
Saw D	Forest Cleaning	4	-12	23	-6
Saw D	Arboriculture	5	-12	25	-6
Saw E	Arboriculture	51	53	33	-7
	Min diff:	-5	-20	-33	-7
	Max diff:	122	56	47	3
	r.m.s diff:	55	27	26	4
Excluding data from Saw A					
	Min diff:	-5	-20	-33	-7
	Max diff:	51	53	47	3
	r.m.s diff:	16	17	25	4

4 DISCUSSION

4.1 ISO 7505 TEST RESULTS

ISO 7505 data has been available to this project in three forms:

- Results from the tests performed on the actual saws used in the study for the three operational modes, idling, cutting and racing.
- Averaged results from the tests performed on the actual saws
- Manufacturer's declared emission data for each type of saw, as printed in the machine's user manual

Each of these three has been used for producing estimates of vibration exposure. However, most users will only have access to the 3rd form, i.e. the values printed in the user manual.

There is one notable discrepancy between the test results for the individual saws and the manufacturers published data: for Saw A, the rear hand, cutting test gave 12.9 m/s², and the overall value for the rear hand was 8.8 m/s², while the manufacturer's published data is 5.9 m/s² for the same hand and 6.9 m/s² for the highest hand.

To allow direct comparison between the in-forest measurements of vibration and the ISO 7505 emission test data, the forest data has been collated according to the equivalent emission test mode (see Table 9). Annex C summarises all the measurement data according to the equivalent emission test modes of idling and cutting. The average data from Annex C is used in Table 21 to determine predicted emission values, from the in-forest vibration measurements.

Table 21 Emission values predicted by forest tests (m/s²).

	Support - top			Throttle			Sum of 1/3rds		
Saw	**Idling**	**Cutting**	**Racing**	**Idling**	**Cutting**	**Racing**	**Front**	**Rear**	**Max**
Saw A	4.4	5.4		4.7	6.0		5.1	5.6	5.6
Saw B	4.1	6.3		4.6	5.7		5.6	5.3	5.6
Saw C	4.5	6.9	N/A	5.5	8.0	N/A	6.1	7.2	7.2
Saw D	3.7	6.9		3.7	6.9		5.8	5.8	5.8
Saw E	3.6	4.0		*3.6*	*4.0*		3.8	*3.8*	3.8
								Average	**5.6**
								Average (excluding saw E)	**6.0**

Figure 5 compares the highest hand averaged data from Table 21 with the equivalent figures from Tables 4 and 13 (the emission values from the ISO 7505 tests for the test saws and the manufacturer's published data).

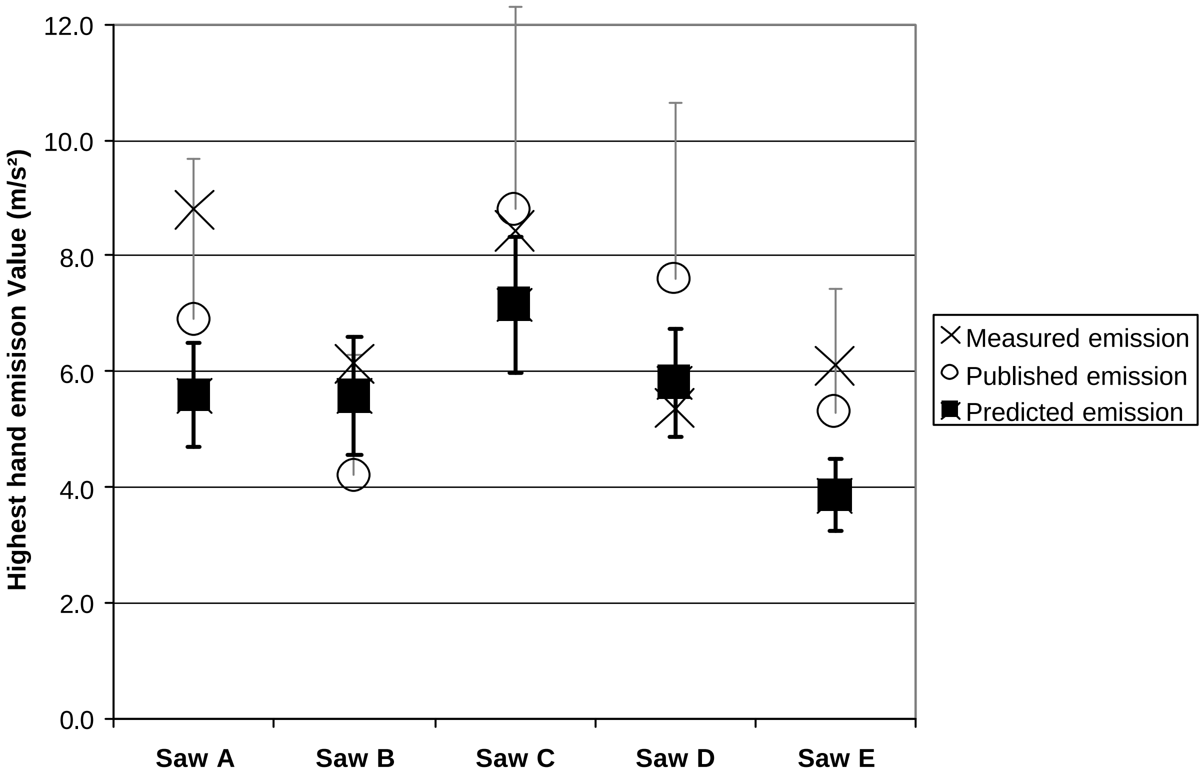


Figure 5 Comparison of predicted emission and measured emission data
(Note – the positive error bars on published emission data represent the uncertainty values *K*)

Table 22 Percentage difference in highest handle emission data from that predicted by in-forest measurements

Saw	Emission average data	Published data
Saw A	58	24
Saw B	10	-25
Saw C	18	23
Saw D	-8	31
Saw E	58	38
average	**27**	**18**

Generally ISO 7505 data over-estimates the values predicted by the in-forest vibration tests. As shown in Table 22, the average difference between individual saw test data and the field predictions is 27%; for the published emission data and field predictions the average difference is 18%.

4.1.1 Verification of declared emission values

EN 12096 defines a method for verification of vibration emission values. If the measured emission of a machine is less than manufacturer's published value, a, plus the uncertainty value, K, then the published emission value is verified. None of the machines used in these tests were declared with uncertainty values, in which case EN 12096 says that values of $K = 0.5a$ should be used if a is less than or equal to 5 m/s², and $K = 0.4a$ for a greater than 5 m/s². Figure 5 shows the K value as the positive error bar on the published emission data values. All of the published emission values were verified by the individual emission tests. However, Saw B was only just within the acceptable range and Saw D was substantially below the published emission value, with the published emission value being more than two standard deviations above the predicted emission value.

It is worth noting that the emission test modes in ISO 7505 are fixed engine speed modes. However, in practice, chainsaws rarely operate at fixed speed for very long; even when idling the engine speed of is often unsteady. In particular, the test mode of racing does not appear to reflect actual operating modes in the forest (therefore no information is available in Table 20 for racing). When machines are revved, it appears to be rapid revving through the entire speed range of the machine. In vibration terms, this will effectively excite every available resonance of the machine, and is likely to generate a very different vibration level to that produced by racing in the ISO 7505 test (i.e. at 133% of the speed of the engine at maximum engine power).

4.2 EXPOSURE TIMES

4.2.1 Dominant modes

Table 6 and Figure 4 show how for most operations, the daily vibration exposures times are dominated by the three modes:

- B3 - two hands on saw vertical cutting under light loads;
- B5 - two hands on saw vertical cutting under heavy loads; and
- C - idling held with the top handle saw resting on the hip/thigh.

For forest clearing operations two other modes become important:

- B1 - two hands on saw idling, saw resting on hip/thigh; and
- B4 - two hands on saw horizontal cutting under light loads.

4.2.2 Nominal exposure times

The relationship between daily vibration exposure and exposure time is given by:

$$A(8) = a_{hv}\sqrt{\frac{T}{\text{EightHours}}}$$

The relationship means that the daily vibration exposure is less sensitive to uncertainty in exposure time than it is to changes in acceleration value. If *p* represents a percentage uncertainty, then

$$p_{A(8)} = \sqrt{p_{ahv}^2 + \frac{p_T^2}{4}}$$

This relationship means that it may be possible to treat exposure time as nominal values; in this study the exposure time values have been rounded to the nearest 10% of 8hours. The data in Table 6 then becomes that shown in Table 16, this greatly simplifies the process of estimating daily vibration exposures.

4.3 IN-FOREST VIBRATION VALUES

Annex D considers whether there is any statistically significant difference between the saw data based on the forest activity modes.

Annex D shows that the saw pairings that may be said to produce statistically significant differences are Saws C from saws A, B and E, and between Saws D and E (although in this later case only at the weaker “probably significant” level).

4.4 RANKING OF CHAINSAWS

One function of ISO 7505 test data is to indicate whether one chainsaw type is lower vibration than another.

This study has gathered data that can provide ranking data, based on in-forest measurements of vibration exposure, predicted emission data, measured emission data and published emission data. For the vibration exposure data, the comparison must be based on arboriculture work, since only this activity used all 5 chainsaws.

Table 23a summarises the data used in this comparison of ranking, Table 23b shows the ranking given by the data in Table 23a

Table 23a Vibration values used for assessing vibration ranking

	Daily exposures Arboriculture $m/s^2A(8)$	Predicted Emission m/s^2	Measured Emission m/s^2	Published Emission m/s^2
Saw A	1.8	5.6	8.8	6.9
Saw B	1.7	5.6	6.1	4.2
Saw C	2.5	7.2	8.4	8.8
Saw D	1.9	5.8	5.4	7.6
Saw E	1.2	3.8	6.1	5.3

Table 23b Vibration ranking (high number = high vibration value)

Saw	Daily exposures Arboriculture rank	Predicted Emission rank	Measured Emission rank	Published Emission rank
Saw A	3	3	5	3
Saw B	2	2	3	1
Saw C	5	5	4	5
Saw D	4	4	1	4
Saw E	1	1	2	2

The two ranking methods based on in-forest measurements give the same ranking result. Although these results are based on the same in-forest vibration data, the exposure data also accounts for exposure times; therefore these methods do not necessarily need to give the same results.

The ranking based on measured emission data shows Saw A as coming last, this result is due to the high values measured for the cutting test, and is not seen in any of the other ranking results.

Generally Saw E ranks consistently as a low-vibration machine, and Saw C ranks consistently as a high vibration machine. Saw B tends to be ranked as a lower vibration machine, and Saw D tends to come out as a higher vibration machine, although the measured emission values put this tool in first place.

It must be noted that some of the values used in this ranking assessment are very close (e.g. saw A and saw B for predicted emission are 5.59 and 5.57m/s²). To assess which saws can be demonstrated to be statistically different, paired-t tests have been performed on the in-forest vibration data (using data grouped by work mode). The details of the analysis are given in Annex D.

Annex D show that there is no statistically significant difference between saws A, B and D. Combining this with the rankings based on the in-forest measurements, gives saw E as the lowest vibration tool, saw C is the highest and, between these, saws A, B and D share an equal ranking.

4.5 METHODS OF ESTIMATING DAILY VIBRATION EXPOSURE

4.5.1 Using measured in-forest vibration values and time-study exposure times

Table 8 shows that for all forest operations, except arboriculture and cross cutting, daily exposure consistently exceed the 2.5 m/s²A(8) exposure action value (EAV) defined in the EU Physical Agents (Vibration) Directive.

In four cases the Physical Agents (Vibration) Directive daily exposure limit value (ELV) of 5 m/s²A(8) is exceeded, these are all for the use of saw C.

For Cross-cutting and arboriculture operations, all exposures are at or below the 2.5 m/s²A(8) EAV.

4.5.2 Using vibration emission mode test data and time-study exposure times

When Tables 8 and 10 are compared, it is noticeable that there are substantial differences relating to saw A. In Table 10, for saw A the exposure estimates are consistently much higher than the 5 m/s²A(8) ELV. This change is due to the high emission test result for cutting for saw A; this emission value is also much higher than the predicted emission data from Table 21 and means that the daily vibration exposure estimates using emission mode data are high for saw A.

This finding is very apparent in Table 20 where the large percentage differences for saw A are noticeable where exposure is calculated using the emission mode data.

4.5.3 Using vibration average emission test data and time-study exposure times

When comparing Tables 10 and 12 with Table 8, the effect of the high emission test result for saw A is apparent, but is less noticeable when the measured average emission values are used in Table 12.

If the results from saw A are excluded for the data, Tables 20 shows that moving to Emission averaged data (Table 12) produces another small increase in the errors of estimation of daily vibration exposure assessment, increasing from 16% to 18% r.m.s. difference.

4.5.4 Using vibration published emission data and time-study exposure times

The published emission data is not affected by the exceptional measured emission values for saw A when cutting. For published emission data and nominal exposure time (Table 17) there is little effect of removing saw A from the analysis.

The error values shown in Table 20 suggest that estimates based on the published data are slightly biased towards overestimates of the daily vibration exposure, but still allow errors as much as +47% and –33%. The r.m.s difference increases to 25%, compared to 16% and 17% for the assessments based on measured emission data.

4.5.5 Using measured in-forest vibration values and nominal exposure times

The use of nominal exposure times, provides a degree of simplification of vibration exposure assessment, without substantially affecting the accuracy of the assessment. Table 17 and the final column in Table 20 show that this simplification in estimating exposure times introduces an error of between –8% and + 3% (r.m.s value of 4%), theses errors are much less than the errors introduced by the use of emission data.

4.6 SIMPLIFIED EXPOSURE ESTIMATION

The objective of this project was to assess whether exposure estimates could be made using an equation of the form:

$$A_e(8) = (a_e + K)C_T$$

In this equation the terms $a_e + K$ effectively represent the in use vibration magnitude, and C_T is related to exposure time. The analysis suggests that, on average, the vibration emission values are close to the average vibration magnitudes; therefore there is no need to use an additional factor K (related to uncertainty of emission data). It is possible to use nominal exposure times, and rounding to the nearest 10% of 8 hours appears to give an acceptable degree of accuracy.

In its simplest form, using the single value average emission value as a_e, then a daily vibration exposure estimate would be given by:

$$A_e(8) = a_e\sqrt{\frac{T_c + T_i}{8hours}}$$

where T_c and T_i are the times spent cutting and idling. Using the percentage times p_c and p_i, gives:

$$A_e(8) = a_e\sqrt{\frac{p_c + p_i}{100}}$$

Using the nominal exposure percentages in Table 10(b), gives the values for the correction factor C_T shown in Table 24.

Table 24 Values for C_T for the forest operations

Operation	$C_T = \sqrt{\frac{p_c + p_i}{100}}$
First thin	0.71
Subs. Thin	0.67
Clear fell(SS)	0.75
Clear fell(pine)	0.74
Brashing	0.75
Cross cutting	0.38
Forest Cleaning	0.81
Arboriculture	0.31

4.7 EXAMPLE OF THE USE OF THE SIMPLIFIED EXPOSURE ESTIMATION METHOD

The C_T values can be used along with manufacturer's emission data to estimate daily exposures, For example: Saw A has a published emission value of 6.9m/s² (Table 13), if it is used in clear felling operations, then multiply the emission value by the appropriate C_T value (0.75 for Sitka Spuce) to give 5.175, rounding this to 1 decimal gives a daily exposure estimate of 5.2m/s²A(8).

If the C_T values in Table 24 are used with the published emission values, then the highest axis values of Table 13 will be reproduced. As shown in Table 20, the differences from the measured daily vibration exposures will range from –33% to +47% (r.m.s value of 25%).

4.8 RECOMMENDATIONS ON THE USE OF THE SIMPLIFIED ESTIMATION METHOD

This study shows that for chainsaws the ISO 7505 emission data is a reasonable indicator of likely vibration magnitude in real forest operations. The emission data can therefore be used to calculate an indication of likely vibration exposures.

The simplified exposure method uses a lookup table of constants for each forest activity. This method is capable of providing a reasonable indication of likely vibration exposure, for tasks where the vibration exposure pattern is similar to those shown in Figure 4 and Table 6.

Where exposure patterns are different to those seen in this study, then assessments of exposure time should be made. It is shown here that time needs to be assessed to the nearest nominal time shown in Table 15, this approximates to an uncertainty of around -30% to +50% on the assessed time and introduces an uncertainty in the assessed vibration exposure of ±7% or less (last column in Table 20).

These simplified exposure assessment methods, based on published ISO 7505 data, might usefully be used as a first stage vibration exposure assessment, to provide an indication of likely exposure, but should not be used as evidence that exposure is below an EAV or ELV, particularly where the predicted exposure value is close to the EAV or ELV.

It is important to note that the results from this study only apply to chainsaws. Evidence from testing on other machine types shows that emission values are generally unreliable indicators of the ranges of vibration magnitudes found in real work situations (S Hewitt and P Brereton 2000, S.M Hewitt and D Smeatham 2000, R Hutt and D Smeatham 2002).

5 CONCLUSIONS

5.1 EMISSION TEST RESULTS

1. All the manufacturer's published emission values were verified according to the definition in EN 12096.
2. For four of the five machines the vibration emission values provided by ISO 7505 tests gave results similar to those predicted by the in-forest measurements.
3. For one machine, Saw A, the ISO 7505 tests on the machine did not correspond to either the in-forest measurements or the manufacturer's published data.
4. For three of the five machines the published vibration emission was more than one standard deviation from the average of those predicted by the in-forest measurements.
5. For Saw D the published vibration emission was more than two standard deviations higher than the average of those predicted by the in-forest measurements

5.2 IN-FOREST TEST RESULTS

6. For the in-forest measurements, saws A, B and D gave results, which were shown to be not significantly different.
7. Saw E (the top-handled saw) and Saw C were shown to be statistically different from the other saws.
8. Ranking test showed that Saw E is the lowest-vibration saw and saw C is the highest, the others share equal ranking.
9. For all forest operations, except arboriculture and cross cutting, daily exposure consistently exceed the 2.5 m/s²A(8) exposure action value (EAV) defined in the EU Physical Agents (Vibration) Directive. In four cases the Physical Agents (Vibration) Directive daily exposure limit value (ELV) of 5 m/s²A(8) is exceeded, these are all for the use of saw C.

5.3 SIMPLIFCATIONS OF EXPOSURE BASED ON PUBLISHED EMISSION VALUES

10. There is some scope for simplification of exposure assessment, using nominal exposure times for job categories, rather than exact exposure times.
11. A table of multiplying values has been produced (Table 24). This can be used for converting emission values to exposure estimates for the eight job categories seen in this study. Use of this table has been shown to result in errors in daily exposure estimates in the range from –34% to +46% when used with published emission data.
12. The use of this simplified exposure assessment methods, based on published ISO 7505 data, might usefully be used as a first stage vibration exposure assessment, to provide an indication of likely exposure, but should not be used as evidence that exposure is below an EAV or ELV, particularly where the predicted exposure value is close to the EAV or ELV.

6 ACKNOWLEDGEMENTS

The author would like to thank:

Mr C Saunders, FR-TDB	For organising and collating the time-study data, and for organising vibration measurement sites and operating chainsaws.
Mr M Mole, HSL	For processing vibration measurement data and assisting with the in-forest vibration measurements.
Mrs S Hewitt, HSL	For assisting with in-forest vibration measurements and reviewing the final text.
Miss A Darby, HSL	For assisting with in-forest vibration measurements.

7 REFERENCES

1. P M Pitts, W Jones, J Hodges, and S Hewitt *Vibration exposure from chain saws Parts 1 - 4* HSE, RLSD Internal reports 1990
2. ISO 7505:1986 "*Forestry machinery - Chain saws - Measurement of hand-transmitted vibration*"
3. European Parliament and the Council of the European Union (2002) Official Journal of the European Communities *Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration).* OJ L177, 6.7.2002, p13.
4. ISO 5349-1:2001 *Mechanical vibration - Measurement and evaluation of human exposure to hand-transmitted vibration - Part 1: General requirements*
5. EN 12096:1997 *Mechanical vibration. Declaration and verification of vibration emission values*
6. Forest Research – Technical Development Branch Contract Report ref 1100A/35/03 *HSL Chainsaw vibration, operator exposure values* November 2003
7. Moroney M J *Facts from figures* Penguin Books 1990 ISBN 0-14-013540-5
8. S Hewitt and P Brereton *Measurement of hand-tool vibration emission and workplace risk* Proceedings of IOA Spring Conference 2000. 17-18 April 2000.
9. S.M Hewitt and D Smeatham *Correlation of vibration emission data with vibration in use - Final Report* HSL Internal Report NV/00/11, June 2000.
10. R Hutt and D Smeatham *The relationship between vibration emission and workplace risk assessment*" Proceedings of IOA Spring Conference 2002. Vol. 24, Pt4.

8 GLOSSARY

Actual exposure time .... See “Exposure time, actual”

Averaged emission data .... See “Emission data, averaged”.

Brashing .... Removing branches up to chest height in a forest (to allow for safe access).

Breast height .... 1.3m above highest ground level at the base of the tree

Clearfell .... Felling all trees in an area of forest.

Crosscutting .... Cutting felled tree stems to specified lengths.

Cutting .... ISO 7505 test mode: cutting through a test log, with the throttle full open and the saw operating at maximum engine power (controlled by the operator’s down force on the saw).

De-buttressing .... Horizontal and vertical cuts at the base of a standing tree, to remove large root off-shoots that are visible above ground level. This process is usually required prior to mechanical harvesting, where these buttresses would obstruct the harvester.

Declared emission value .... The result from a standardised vibration test on a machine published by the manufacturer in the machine’s handbook. Usually a vibration emission test is performed in controlled operating conditions, and repeated with more than one operator.

Delimbing .... Removing branches from stem (see brashing and snedding)

EAV .... “Exposure action value”, defined in the Physical Agents (Vibration) directive as 2.5 $m/s^2A(8)$ for hand-arm vibration. A value at or above which workers should not be exposed

ELV .... “Exposure limit value”, defined in the Physical Agents (Vibration) directive as 5 $m/s^2A(8)$ for hand-arm vibration. A value at or above which actions must be taken to reduce and manage exposure.

Emission data, Average .... The average of the vibration from the three emission modes defined in ISO 7505, i.e.: the average of the “idling”, “cutting” and “racing” tests. This is the value that is the declared emission value for chainsaws.

Emission mode data .... ISO 7507 emission test data from individual test modes, i.e. the data from each test mode “idling”, “cutting” and “racing”.

Emission modes .... The vibration emission test for chain saws is based on an average result from three operating modes: “idling”, “cutting” and “racing”.

Exposure time .... The exposure time of an operator to a machine, usually while operating in a specified mode.

Exposure time, actual .... Used in this report to refer to the exposure time assessed from time studies.

Exposure time, nominal .... The actual exposure time rounded to convenient “simple” durations (e.g. 2 hours, ½ hour, 15 mins).

Felling (cuts)........................... Use of the chain saw to cut through the base of the standing tree. These usually consist of three cuts, two vertical and horizontal, to create the triangular cross-section "gob" at the front of the tree, and the final horizontal cut from the back of the tree, to leave just the hinge, about which the tree falls.

Hand position – support .... Same as "hand-position – front". For in-forest measurement this position is further clarified by either "top" or "side", where "top" represents the normal left-hand position with the saw held for vertical cuts, and "side" represents the normal left-hand position with the saw held for horizontal cuts.

Hand position – Throttle .... Same as "hand-position – rear" (the right-hand position)

Idling...................................... 1) ISO 7505 test mode: saw idling at speed specified by the manufacturer.
2) During forest use: the saw is running but the throttle is not being held.

Job type .... General name for the type of forestry work being undertaken (e.g. "General thinning", "Arboriculture")

Nominal exposure time .... See "Exposure time, nominal"

Predicted emission values .... An emission value based on the in-forest measurement of vibration during normal use. The results for the idling and cutting modes are substituted by in-forest data from activities that correspond to idling or cutting activities (for the purpose of the predicted emission, racing is assumed to be the same as cutting)

Published emission data........... The ISO 7505 results published by the chain saw manufactures for the five saws used in this study (see also "declared emission value".

Racing.................................... ISO 7505 test mode: the saw speed is set to 133% of the saw speed at maximum power or its maximum speed (whichever is less).

Revving.................................. During forest use: running the saw under no load, usually with rapid changes to the throttle setting.

Snedding................................. Removing branches from felled trees, to provide access to the stem

Stem....................................... Trunk of tree

Thinning operations................. Felling saplings and young trees to provide greater forest space for the crop.

Vibration emission .... The vibration produced by the machine while operating (units: m/s^2)

Vibration exposure .... The total daily exposure to vibration of a machine operator. The units for exposure are expressed as "$m/s^2A(8)$" to distinguish them from vibration emission values.

ANNEX A CHAINSAW DETAILS

Note – the information on engine size, power, guide-bar range, weight and emission values given in this annex is generic information for the chainsaw type, obtained from the manufacturer's web site or instruction manual.

A.1 SAW A

HSL Sample ID	NV/02/45
Engine size	45cm³
Power	2.4kW
Guide bar range	41-46cm
Weight without chain and bar	4.9kg
Declared emission values	Left (front) hand: 5.9 m/s² Right (rear) hand: 6.9 m/s²

A.2 SAW B

HSL Sample ID	NV/02/46
Engine size	56.5 cm³
Power	3.2 kW
Guide bar range	33 - 60 cm
Weight without chain and bar	5.5 kg
Declared emission values	Front: 3.9 m/s² Rear: 4.2 m/s²

A.3 SAW C

HSL Sample ID	NV/02/47
Engine size	49.3 cm³
Power	2.6 kW
Guide bar range	38 - 50 cm
Weight without chain and bar	4.9 kg
Declared emission values	8.8 m/s²

A.4 SAW D

HSL Sample ID	NV/02/48
Engine size	48.7 cm³
Power	2.6 kW
Guide bar range	37 - 40 cm
Weight without chain and bar	4.7 kg
Declared emission values	Front: 6.9 m/s² Rear: 7.6 m/s²

A.5 SAW E

HSL Sample ID	NV/02/49
Engine size	35.2 cm^3
Power	1.7 kW
Guide bar range	30 - 35 cm
Weight without chain and bar	3.5 kg
Declared emission values	Front: 3.4 m/s^2 Rear: 5.3 m/s^2

ANNEX B HAND-ARM VIBRATION FOREST MEASUREMENTS

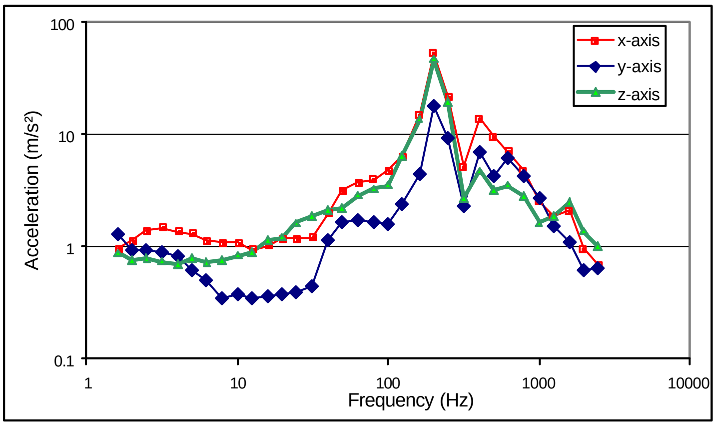
B.1 SAMPLE OF ANALYSIS – SHOWING DETAIL OF FREQUENCY ANALYSIS

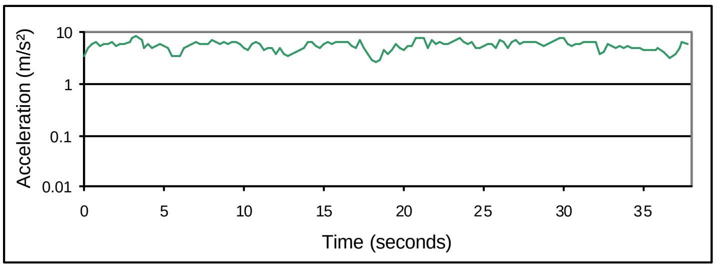
MeasurementID	75	*Date*	12/03/2003		
SiteID	1	*DATTapeNo*	2	*VideoNumber*	2
InstrumentSetUpID	4	*DATIDNumber*	1		
ReportID		*DATStartTime*	10:24:52	*VideoStart time*	10:24:52
ResultsID	212	*DATStopTime*	10:25:30	*VideoStop time*	10:25:30
Duration	00:00:38	*Continuousoperation?*	n		
Machine:	Echo CS-5100				
Activity	Snedding				
HandPosition:	Rear handle	*Comments*	Brief pause to idling with saw on tree, in middle of this period		
Handleft/right:	r				

Freq	**X-axis**	**Y-axis**	**Z-axis**	
1.6	0.98	1.29	0.89	
2	1.12	0.94	0.76	
2.5	1.42	0.94	0.81	
3.15	1.47	0.91	0.74	
4	1.37	0.85	0.71	
5	1.30	0.62	0.80	
6.3	1.12	0.51	0.72	
8	1.09	0.36	0.76	
10	1.11	0.38	0.84	
12.5	0.96	0.35	0.92	
16	1.02	0.37	1.16	
20	1.18	0.38	1.22	
25	1.20	0.39	1.66	
31.5	1.21	0.44	1.88	
40	2.01	1.14	2.15	
50	3.17	1.66	2.21	
63	3.84	1.72	2.89	
80	4.05	1.65	3.29	
100	4.76	1.61	3.55	
125	6.47	2.40	6.36	
160	15.33	4.37	13.96	
200	53.68	18.02	47.33	
250	22.20	9.38	19.60	
315	5.22	2.34	2.76	
400	14.06	7.09	4.80	
500	9.83	4.27	3.20	
630	7.02	6.11	3.57	
800	4.72	4.30	2.86	
1000	2.58	2.70	1.66	
1250	1.85	1.55	1.91	
1600	2.11	1.10	2.48	
2000	0.97	0.61	1.37	
2500	0.69	0.64	1.04	
ahw:	5.84	2.13	5.23	m/s²
ahv:		**8.12**	**m/s²**	

Sensitivities (mV/(m/s²)):

x1	*y1*	*z1*
10	*10*	*10*





B.2 SUMMARY OF VIBRATION TOTAL VALUES FROM IN-FOREST MEASUREMENTS

Table B.1a Saw A

Saw	Hand	Activity code	Count	Minimum	Maximum	Average	StdDev
Saw A							
	Support - side						
		B1	7	3.27	9.13	5.98	1.96
		B2	27	5.03	8.39	6.81	0.90
		B4	6	2.73	6.40	4.42	1.18
		B5	12	4.96	11.15	6.12	1.83
		C	5	4.61	9.94	6.37	2.10
	Support - side Total		57	2.73	11.15	6.27	1.55
	Support - top						
		B1	2	3.84	5.13	4.48	0.91
		B3	29	4.73	7.63	5.68	0.62
		B4	4	4.58	6.84	5.83	0.98
		B5	18	3.14	8.45	4.88	1.31
		C	1	4.34	4.34	4.34	
		C1	1	4.12	4.12	4.12	
	Support - top Total		55	3.14	8.45	5.33	1.01
	Throttle						
		B1	7	3.33	5.94	4.70	1.05
		B3	46	4.58	8.62	6.29	1.10
		B4	11	4.95	7.42	6.05	0.88
		B5	31	3.28	9.95	5.63	1.49
	Throttle Total		95	3.28	9.95	5.93	1.29
Saw A Total			207	2.73	11.15	5.87	1.34

Table B.1b Saw B

Saw	Hand	Activity code	Count	Minimum	Maximum	Average	StdDev
Saw B							
	Support - side						
		B	3	1.65	2.64	2.29	0.55
		B1	8	3.22	6.20	4.22	0.97
		B2	32	3.00	10.37	6.39	1.52
		B4	15	2.41	6.60	4.06	1.02
		B5	9	3.05	9.85	5.82	2.50
		C	2	3.65	5.35	4.50	1.20
		C1	1	4.54	4.54	4.54	
	Support - side Total		70	1.65	10.37	5.32	1.89
	Support - top						
		B1	8	2.09	4.26	3.49	0.66
		B3	36	3.53	8.38	6.36	1.25
		B4	14	5.53	11.34	7.14	1.39
		B5	17	3.17	7.82	5.43	1.46
		C	3	3.99	6.44	4.90	1.34
		C1	3	3.41	5.78	4.85	1.26
		C3	1	4.69	4.69	4.69	
	Support - top Total		82	2.09	11.34	5.89	1.61
	Throttle						
		B	1	3.58	3.58	3.58	
		B1	4	1.47	6.01	4.58	2.10
		B3	61	3.13	10.28	6.46	1.20
		B4	14	3.20	5.35	4.43	0.73
		B5	27	3.30	8.38	4.52	1.20
		C3	2	2.58	6.64	4.61	2.87
	Throttle Total		109	1.47	10.28	5.59	1.55
Saw B Total			261	1.47	11.34	5.61	1.67

Table B.1c Saw C

Saw	Hand	Activity code	Count	Minimum	Maximum	Average	StdDev
	Saw C						
	Support - side						
		B1	2	3.9	5.4	4.7	1.1
		B4	3	4.8	6.3	5.4	0.8
	Support - side Total		5	3.9	6.3	5.1	0.9
	Support - top						
		B1	10	2.1	6.1	4.0	1.2
		B3	71	4.5	10.1	7.0	1.1
		B4	16	3.9	9.7	6.8	1.4
		B5	29	4.9	10.3	6.8	1.4
		C	4	4.7	6.0	5.3	0.6
		C1	3	3.9	5.7	5.0	1.0
	Support - top Total		133	2.1	10.3	6.6	1.4
	Throttle						
		B1	7	2.2	7.4	6.0	1.8
		B3	28	6.5	10.3	8.4	0.9
		B4	7	4.3	8.7	6.5	1.5
		B5	20	5.5	10.9	7.9	1.5
		C3	2	1.5	5.6	3.6	2.9
	Throttle Total		64	1.5	10.9	7.6	1.7
Saw C Total			202	1.5	10.9	6.9	1.6

Table B.1d Saw D

Saw	Hand	Activity code	Count	Minimum	Maximum	Average	StdDev
	Saw D						
	Support - side						
		B1	8	3.88	8.66	6.19	1.91
		B2	20	4.61	9.25	6.37	1.15
		B4	4	5.25	7.93	6.23	1.27
		B5	7	4.65	8.65	5.96	1.36
		C	3	4.77	8.10	6.82	1.80
	Support - side Total		42	3.88	9.25	6.28	1.35
	Support - top						
		B1	4	2.89	4.25	3.76	0.64
		B3	27	5.16	9.76	6.73	1.14
		B4	10	6.48	11.15	8.42	1.43
		B5	14	5.02	7.66	5.96	0.68
		C	1	3.51	3.51	3.51	
		C1	3	3.19	4.22	3.72	0.51
	Support - top Total		59	2.89	11.15	6.42	1.68
	Throttle						
		B1	5	1.44	10.30	6.36	3.72
		B3	30	4.59	10.38	6.33	1.41
		B4	20	2.01	8.97	6.26	1.89
		B5	25	2.77	10.88	5.89	2.36
		C2	1	5.54	5.54	5.54	
		C3	1	2.84	2.84	2.84	
	Throttle Total		82	1.44	10.88	6.13	2.02
Saw D Total			183	1.44	11.15	6.26	1.77

Table B.1e Saw E

Saw	Hand	Activity code	Count	Minimum	Maximum	Average	StdDev
Saw E							
	Support - side						
		B1	5	4.40	9.04	6.28	1.72
		B2	10	4.29	10.03	7.40	2.18
		B4	2	9.81	9.93	9.87	0.08
		B5	20	5.00	9.72	6.86	1.34
		C	1	5.03	5.03	5.03	
	Support - side Total		38	4.29	10.03	7.04	1.75
	Support - top						
		B1	4	2.47	3.67	2.97	0.51
		B3	12	2.92	5.74	3.66	0.75
		B5	27	2.99	6.04	4.10	0.80
		C	2	3.98	4.10	4.04	0.08
		C1	2	3.55	6.00	4.77	1.73
		C2	1	2.74	2.74	2.74	
		C3	2	3.26	4.25	3.75	0.70
	Support - top Total		50	2.47	6.04	3.89	0.85
	Throttle (same as support - top)						
		B1	*4*	*2.47*	*3.67*	*2.97*	*0.51*
		B3	*12*	*2.92*	*5.74*	*3.66*	*0.75*
		B5	*27*	*2.99*	*6.04*	*4.10*	*0.80*
		C	*2*	*3.98*	*4.10*	*4.04*	*0.08*
		C1	*2*	*3.55*	*6.00*	*4.77*	*1.73*
		C2	*1*	*2.74*	*2.74*	*2.74*	
		C3	*2*	*3.26*	*4.25*	*3.75*	*0.70*
	Support - top Total		*50*	*2.47*	*6.04*	*3.89*	*0.85*
Saw E Total			88	2.47	10.03	5.25	2.04

ANNEX C PREDICTION OF EMISSION VALUES

C.1 PREDICTION OF VIBRATION EMISSION VALUES FROM IN-FOREST DATA

Table C1 summarises the data from in-forest test, with results grouped according to the equivalent emission test modes of idling and cutting (none of the in-forest activities were judged to have been equivalent to the third test mode of racing).

Table C.1 Summary of data values relating to idling and cutting equivalent modes

Saw	Hand	Equivalent mode	Count	Min	Max	Average	StdDev
Saw A	Support - side	Cutting	45	2.73	11.15	6.31	1.45
		Idling	12	3.27	9.94	6.14	1.93
	Support - top	Cutting	51	3.14	8.45	5.41	1.01
		Idling	4	3.84	5.13	4.36	0.55
	Throttle	Cutting	88	3.28	9.95	6.03	1.26
		Idling	7	3.33	5.94	4.70	1.05
Saw B	Support - side	Cutting	59	1.65	10.37	5.51	1.97
		Idling	11	3.22	6.20	4.30	0.91
	Support - top	Cutting	67	3.17	11.34	6.29	1.44
		Idling	15	2.09	6.44	4.13	1.10
	Throttle	Cutting	103	3.13	10.28	5.65	1.50
		Idling	6	1.47	6.64	4.59	2.07
Saw C	Support - side	Cutting	3	4.77	6.32	5.41	0.81
		Idling	2	3.87	5.43	4.65	1.10
	Support - top	Cutting	116	3.92	10.33	6.92	1.20
		Idling	17	2.11	6.08	4.49	1.14
	Throttle	Cutting	55	4.29	10.87	7.99	1.39
		Idling	9	1.50	7.43	5.47	2.16
Saw D	Support - side	Cutting	31	4.61	9.25	6.26	1.19
		Idling	11	3.88	8.66	6.36	1.81
	Support - top	Cutting	51	5.02	11.15	6.85	1.37
		Idling	8	2.89	4.25	3.71	0.51
	Throttle	Cutting	75	2.01	10.88	6.17	1.88
		Idling	7	1.44	10.30	5.74	3.31
Saw E	Support - side	Cutting	32	4.29	10.03	7.22	1.74
		Idling	6	4.40	9.04	6.07	1.62
	Support - top	Cutting	39	2.92	6.04	3.97	0.80
		Idling	11	2.47	6.00	3.62	0.99
Grand Total			941	1.44	11.34	6.04	1.74

ANNEX D STATISTICAL ANALYSIS OF SAW MODE DIFFERENCES

D.1 FOREST ACTIVITY MODES

Table D.1 uses the values from Table 4 to compare the results from the forest activities (in cases where data is available for all saws).

Table D.1 Average acceleration values in m/s² for forest activity modes

Handle	Mode	Saw A	Saw B	Saw C	Saw D	Saw E
Support - side	B1	5.98	4.22	4.65	6.19	6.28
Support - side	B4	4.42	4.06	5.41	6.23	9.87
Support - top	B1	4.48	3.49	4.03	3.76	2.97
Support - top	B3	5.68	6.36	6.99	6.73	3.66
Support - top	B5	4.88	5.43	6.79	5.96	4.10
Support - top	C	4.34	4.90	5.27	3.51	4.04
Support - top	C1	4.12	4.85	5.01	3.72	4.77
Throttle	B1	4.70	4.58	6.02	6.36	2.97
Throttle	B3	6.29	6.46	8.43	6.33	3.66
Throttle	B5	5.63	4.52	7.92	5.89	4.10

There are clearly similarities between the test results for the five saws. Table D.2 provides a statistical analysis of the results in Table D.1, to see whether any pairs of data sets are significantly different.

A t-test (Moroney) has been used in Table D.2, to assess whether the results from one saw is significantly different from the results from another. The result are expressed as:

- ? "Highly significant" equivalent to a probability factor result less than 0.1%,
- ? "Significant" equivalent to a probability factor result less than 1%,
- ? "Probably significant" equivalent to a probability factor result less than 5% or
- ? "Not significant" equivalent to a probability factor result 5% or more.

Where the results are shown as being "not significant", then the results from the two saws are statistically the same.

Table D.2 t-test analysis of differences between saws based on forest activity modes

Saw	mean difference	Variance (s^2)	t	Probability (%)	Significance
Differences from saw A					
Saw B	0.06	0.48	0.22	82.85	Not significant
Saw C	1.29	0.68	4.14	0.32	Significant
Saw D	0.27	0.73	0.82	43.46	Not significant
Saw E	-1.23	0.95	3.34	1.03	Probably significant
Differences from saw B					
Saw C	1.23	1.00	3.26	1.16	Probably significant
Saw D	0.21	1.05	0.54	60.71	Not significant
Saw E	-1.29	0.92	3.55	0.75	Significant
Differences from saw C					
Saw D	-1.03	0.73	3.18	1.29	Probably significant
Saw E	-2.52	2.09	4.62	0.17	Significant
Differences from saw D					
Saw E	-1.50	2.34	2.59	3.23	Probably significant

The results from Table D.2 are summarised in Table D.3. The Table shows that:

? Saws C may be said to produce statistically significant differences from all the other saws (although only the differences C – B and C – D are at the weaker "probably significant" level)

? Saw E may be said to produce statistically significant differences from all the other saws (although only the differences E – A and E – D are at the weaker "probably significant" level)

? The differences between Saws A, B and D are statistically not significant.

Table D.3 Summary of significance results

	SawA	SawB	SawC	SawD
SawB	*Not significant*			
SawC	**Significant**	Probably significant		
SawD	*Not significant*	*Not significant*	Probably significant	
SawE	Probably significant	**Significant**	**Significant**	Probably significant

INDEX TO TABLES AND FIGURES