

# Application of low-cost accelerometers for measurement of whole body vibrations

Pasan Hettiarachchi Adrian Gomez Peter Johansson

AMM - Uppsala





# Whole body vibrations (WBV) and health risks



- What're whole body vibrations
  - Usually occur while operating vehicles
  - Leads to lower back pain and neck pain
  - 10% of the male working population of Sweden is subjected to whole body vibrations at least ¼ of the working time
  - Among blue-collar workers this could be as high as 25%







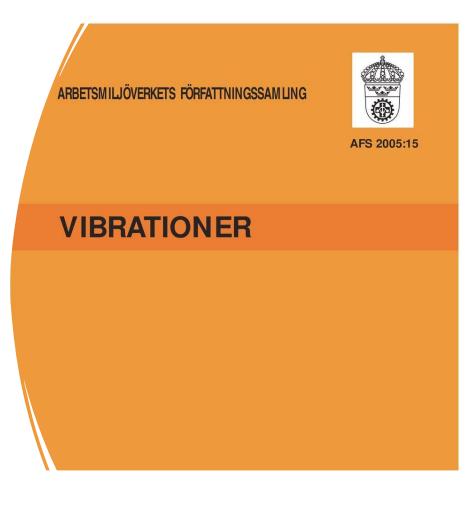
What does the Swedish work environment law demand?

• AFS 2001:1, 8 §

The employer must regularly examine the working conditions and assess the risks ...

• AFS 2005:15, 4-7 § §

...that may arise as a result of exposure to vibrations at work.





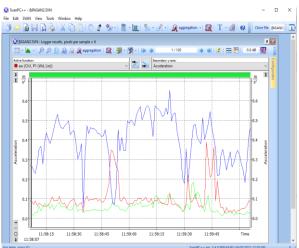


#### UPPSALA UNIVERSITET

### Typical whole body vibration risk assessment

- Find daily vibration dose levels
- Check whether they exceed "Action" or "Limit" values
- Take remedial actions (immediate if necessary)





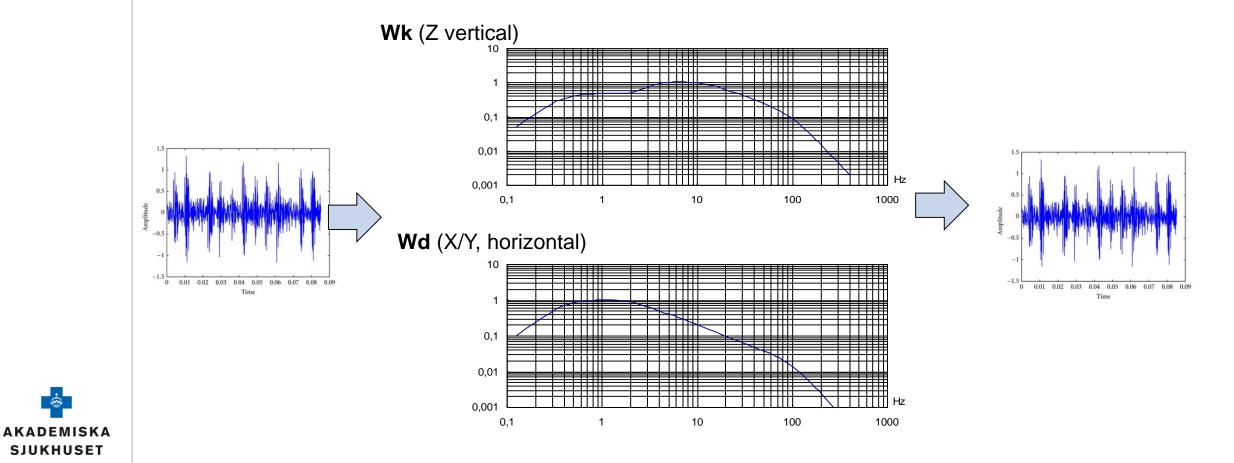






#### WBV exposure calculation – Step 1

## Frequency weighted filtering according to iso2631 WBV-filter specifications





#### WBV exposure calculation – Step 2

$$a_{w} = \sqrt{\frac{1}{T} \int_{0}^{T} a_{w}^{2}(t) dt}$$
$$A(8) = a_{w} \sqrt{\frac{T}{T_{0}}}$$
$$A(8) = \sqrt{A_{1}(8)^{2} + A_{2}(8)^{2} + \dots}$$

40	267	800	1600		6400	9600	12800		19200	25600	3200
30	150	450	900	1800	3600	5400	7200	9000	10800	14400	
25	104	313	625	1250	2500	3750	5000	6250	7500	10000	1250
20	67	200	400	800	1600	2400	3200	4000	4800	6400	8000
19	60	181	361	722	1444	2166	2888	3610	4332	5776	7220
18	54	162	324	648	1296	1944	2592	3240	3888	5184	6480
17	48	145	289	578	1156	1734	2312	2890	3468	4624	5780
16	43	128	256	512	1024	1536	2048	2560	3072	4096	5120
15	38	113	225	450	900	1350	1800		2700	3600	4500
14	33	98	196	392	784	1176	1568	1960	2352	3136	3920
13	28	85	169	338	676	1014	1352	1690	2028	2704	
12	24	72	144	288	576	864	1152	1440	1728	2304	2880
11	20	61	121	242	484	726	968		1452	1936	2420
10	17	50	100	200	400	600	800	1000	1200	1600	2000
9	14	41	81	162	324	486	648	810	972	1296	1620
8	11	32	64	128	256	384	512	640	768	1024	1280
7	8	25	49	98	196	294	392	490	588	784	980
6	6	18	36	72	144	216	288	360	432	576	720
5,5	5	15	30	61	121	182	242	303	363	484	605
5	4	13	25	50	100	150	200	250	300	400	500
4,5	3	10	20	41	81	122	162	203	243	324	405
4	3	8	16	32	64	96	128	160	192	256	320
3,5	2	6	12	25	49	74	98	123	147	196	245
3	2	5	9	18	36	54	72	90	108	144	180
2,5	1	3	6	13	25	38	50	63	75	100	125
2	1	2	4	8	16	24	32	40	48	64	80
	5 min	15 min	30 min	1h	2h	3h	4h	5h	6h	8h	10h

$$VDV = \{\int_{0}^{T} [a_{w}(t)]^{4} dt\}^{4}$$

$$VDV_{total} = \left(\sum_{i} VDV_{i}^{4}\right)^{4}$$

Daily WBV Exposure

Daily exposure points

**Optional VDV exposure** 



"





Why not enough WBV measurements? Is it cost and complexity of equipment? Can we use cheap wearable accelerometers?



#### Axivity AX3

- Cheap (129 €)
- No cables self contained
- Small, robust and handy (23 X 32.5 X 7.6 m with IPx8 and IP6x)





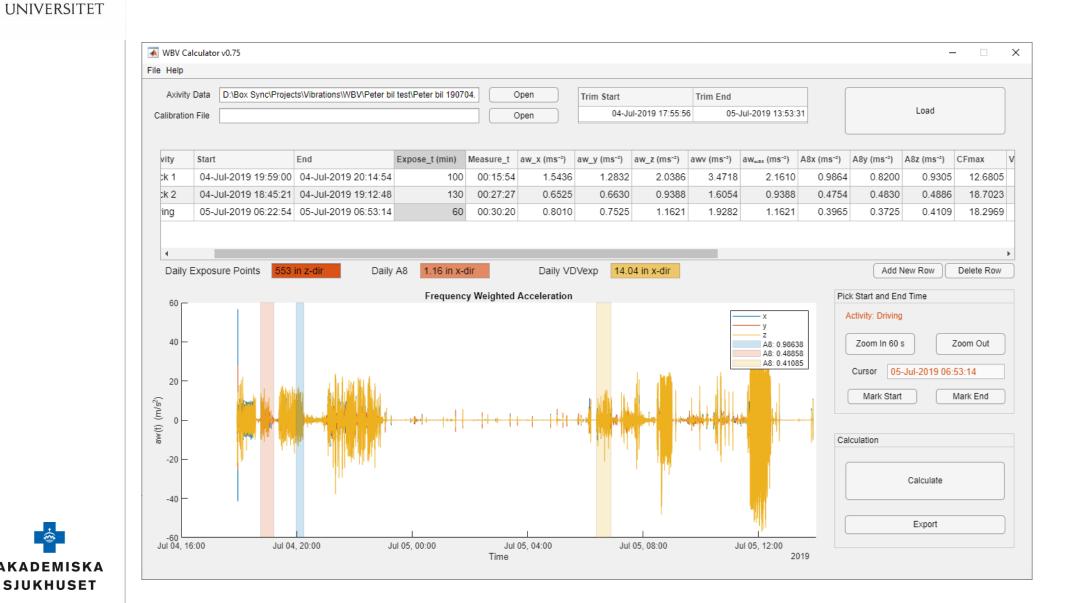
Introducing Axivity AX3 based WBV Calculator – A tool to measure whole body vibration exposure

	A A A A A A A A A A A A A A A A A A A		
WBV Calculator v0.75 File Help		- 🗆 X	
Axivity Data D:\Box Sync\Projects\Vibrations\WBV\Peter bil te	VPeter bil 190704. Open Trim Start Trim End		
Calibration File	Open 04-Jul-2019 17:55:56 05-Jul-2019 13:53:31	Load	
vity     Start     End     E:       :k 1     04-Jul-2019 19:59:00     04-Jul-2019 20:14:54     20:04-Jul-2019 19:12:48       :k 2     04-Jul-2019 18:45:21     04-Jul-2019 19:12:48     20:05-Jul-2019 06:53:14	Measure_t     aw_x (ms <sup>-2</sup> )     aw_y (ms <sup>-3</sup> )     aw_z (ms <sup>-3</sup> )     awy (ms <sup>-3</sup> )     aw_{max} (ms <sup>-3</sup> )     At       100     00:15:54     1.5436     1.2832     2.0386     3.4718     2.1610       130     00:27:27     0.6525     0.6630     0.9388     1.6054     0.9388       60     00:30:20     0.8010     0.7525     1.1621     1.9282     1.1621	A8y (ms <sup>-1</sup> )     A8z (ms <sup>-1</sup> )     CFmax     V       0.9864     0.8200     0.9305     12.6805       0.4754     0.4830     0.4886     18.7023       0.3965     0.3725     0.4109     18.2969	
▲ Daily Exposure Points 553 in z-dir Daily Ai	1.16 in x-dir Daily VDVexp 14.04 in x-dir	Add New Row Delete Row	
Daily Exposure Points Dog in Z-oir Daily A	The in x-dir     Daily VD vexp     14.04 in x-dir       Frequency Weighted Acceleration     Frequency Weighted Acceleration     Frequency Weighted Acceleration	Pick Start and End Time	
60 40 -20 -20 -20 -20 -20 -20 -20 -2	00:00 Jul 05, 04:00 Jul 05, 08:00 Jul 05, 12:00 2019	Activity: Driving Zoom In 60 s Zoom Out Cursor 05-Jul-2019 06:53:14 Mark Start Mark End Calculation Calculate Export	

AKADEMISKA SJUKHUSET



#### User friendly GUI







#### UPPSALA UNIVERSITET

#### User Interface – Output: Exposure details

Activity	Start		End		Expose_t (min)	Measure_t	aw_x (ms-2)	aw_y (ms-2)	aw_z (ms-²)	awv (ms-2)	aw <sub>max</sub> (n	ns-²) /	48x (I
5 Truck 1	04-Ju	ul-2019 19:5	/9:00 04-J	ul-2019 20:14:	54 100	0 00:15:54	1.5436	1.2832	2.0386	3.471	8 2.	.1610	0
Truck 2	04-Ju	ul-2019 18:4	5:21 04-J	ul-2019 19:12:	48 130	0 00:27:27	0.6525	0.6630	0.9388	1.605	4 0.	.9388	C
5 Driving	05-Ju	ul-2019 06:2	2:54 05-J	ul-2019 06:53:	14 60	0 00:30:20	0.8010	0.7525	1.1621	1.928	2 1.	.1621	0
										-			
ns <sup>-2</sup> ) A8x	(ms <sup>-2</sup> ) A	48y (ms-2)	A8z (ms-2)	CFmax V	DVmax (ms-1175)	VDVx (ms-1175)	VDVy (ms-11)	*) VDVz (ms	Point	s_x Poi	nts_y	Points_	z
									0.450	400	400		
6	6 Truck 1 6 Truck 2 6 Driving	6 Truck 1 04-Ju 6 Truck 2 04-Ju 6 Driving 05-Ju ms <sup>-2</sup> ) A8x (ms <sup>-2</sup> ) A	6 Truck 1 04-Jul-2019 19:59 6 Truck 2 04-Jul-2019 18:49 6 Driving 05-Jul-2019 06:22 ms <sup>-2</sup> ) A8x (ms <sup>-2</sup> ) A8y (ms <sup>-2</sup> )	6 Truck 1 04-Jul-2019 19:59:00 04-Ju 6 Truck 2 04-Jul-2019 18:45:21 04-Ju 6 Driving 05-Jul-2019 06:22:54 05-Ju ms <sup>-2</sup> ) A8x (ms <sup>-2</sup> ) A8y (ms <sup>-2</sup> ) A8z (ms <sup>-2</sup> )	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:5     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:4     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:1     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8y (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   V	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8y (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*75</sup> )   1	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8y (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*79</sup> )   VDVx (ms <sup>-1*79</sup> )	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20   0.8010     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*79</sup> )   VDVx (ms <sup>-1*79</sup> )   VDVy (ms <sup>-1*79</sup> )	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436   1.2832     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525   0.6630     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20   0.8010   0.7525     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*79</sup> )   VDVx (ms <sup>-1*79</sup> )   VDVy (ms <sup>-1*79</sup> )   VDVz (ms <sup>-1*79</sup> )	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436   1.2832   2.0386     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525   0.6630   0.9388     6   Driving   05-Jul-2019 06:53:14   60   00:30:20   0.8010   0.7525   1.1621	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436   1.2832   2.0386   3.471     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525   0.6630   0.9388   1.605     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20   0.8010   0.7525   1.1621   1.928     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*79</sup> )   VDVx (ms <sup>-1*79</sup> )   VDVz (ms <sup>-1*79</sup> )   VDVz (ms <sup>-1*79</sup> )   Points_x   Points_x   Points_x	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436   1.2832   2.0386   3.4718   2.0386     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525   0.6630   0.9388   1.6054   0.0     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20   0.8010   0.7525   1.1621   1.9282   1.0     ms <sup>-2</sup> )   A8x (ms <sup>-2</sup> )   A8z (ms <sup>-2</sup> )   CFmax   VDVmax (ms <sup>-1*79</sup> )   VDVy (ms <sup>-1*79</sup> )   VDVz (ms <sup>-1*79</sup> )   Points_x   Points_y	6   Truck 1   04-Jul-2019 19:59:00   04-Jul-2019 20:14:54   100   00:15:54   1.5436   1.2832   2.0386   3.4718   2.1610     6   Truck 2   04-Jul-2019 18:45:21   04-Jul-2019 19:12:48   130   00:27:27   0.6525   0.6630   0.9388   1.6054   0.9388     6   Driving   05-Jul-2019 06:22:54   05-Jul-2019 06:53:14   60   00:30:20   0.8010   0.7525   1.1621   1.9282   1.1621

11.4636

12.2421

16,7601

18.7285

81

61

81

61

9.0342

9.3034

81

72

16.7601

18.7285



054

282

0.9388

1.1621

0.4754

0.3965

0.4830

0.3725

0.4886

0.4109

18,7023

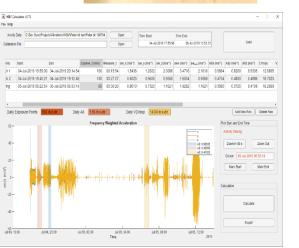
18.2969



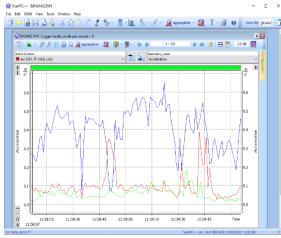
Field validation: Axivity AX3 based system vs Gold standard Svantek SV106

- Purpose:
  - Validating our system in real scenarios: compare AX3 based system in the field with a gold standard measurement system













AKADEMISKA SJUKHUSET

## Field validation: – a timber production company

- Multiple wheel-loaders
- A control-room (with low vibrations)
- 16 measurements: AX3s fixed on top of SV106's seat plate

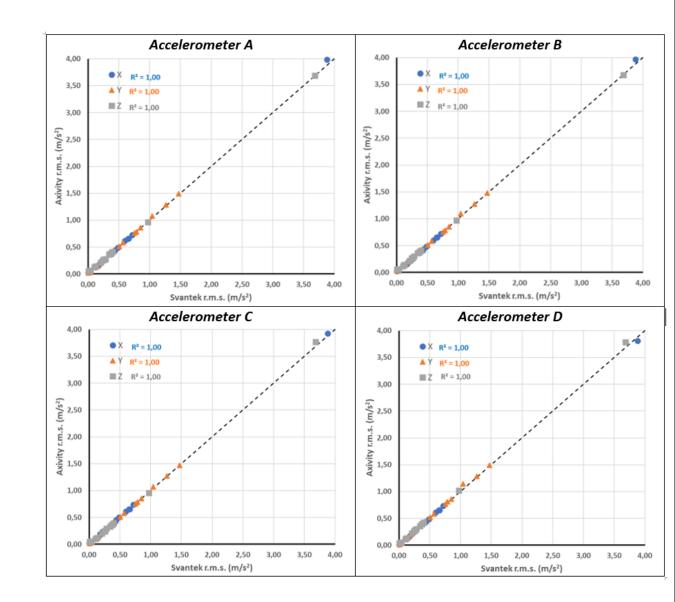






### RMS (a<sub>w</sub>) Comparison

- Very good correlation with Svantek
- Largest mean difference (bias) between AX3 and SV 106 was 0.02 m/s<sup>2</sup>

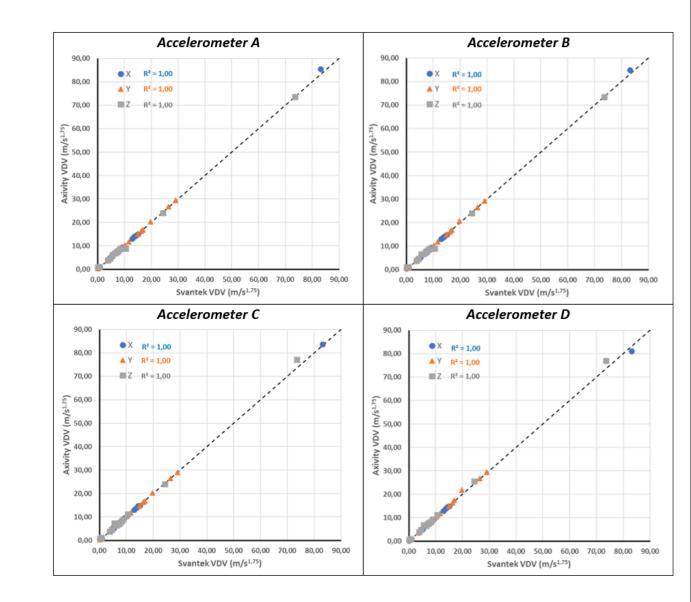






#### **VDV** Comparison

- Good correlation with Svantek
- Largest mean difference (bias) between AX3 and SV 106 was 0.56 m/s<sup>1,75</sup>







#### Final Remarks

- Field measurements with the AX3 and our software can be a sufficiently reliable method for risk assessments of WBV at work.
- A WBV measurement can be done fairly easily and at a low cost.

