

Regulations define Occupational Exposure Limits (OELs) as sharp limits which must never be exceeded. Unfortunately, exposure doesn't behave that way. While it is relatively easy to demonstrate non-compliance, it is much more difficult to demonstrate compliance because exposure distributions have a long upper tail, meaning that there is always a possibility of finding an exposure which exceeds the relevant OEL. There is therefore always a chance that a next measure will exceed the OEL, it is just a question of time before it happens. In order to address this uncertainty, different sampling strategies have been developed to evaluate whether this chance is small enough to be ignored. In 2011, The British and Dutch Occupational Hygiene Societies (BOHS and DOHS or NVvA) jointly published an innovative sampling strategy, which also included both group and individual compliance testing. The document can be downloaded from both society websites www.bohs.org and www.arbeidshygiene.nl. Further background is provided in Ogden and Lavoué (Testing Compliance with Occupational Exposure Limits: development of the British-Dutch Guidance, JOEH 2012, 9, D63-D70). The guidance itself is a lengthy 50-page document, in which the last 20 pages are dedicated to an appendix describing how all the necessary calculations can be performed in Microsoft Excel. Since this procedure is quite complex, time-consuming and prone to error, a Microsoft Excel tool called BWStat has been developed to perform all the necessary calculations.

Results and discussion

A macro-free multi-language Microsoft Excel spreadsheet.

Since the guidance describes how to perform the calculations in Microsoft Excel, it is the obvious choice for building a spreadsheet-based statistical tool for occupational hygiene compliance testing. Microsoft Excel is universal, and most personal computers and laptops will have it in their configuration. Since many employers do not allow the use of macro-containing spreadsheets and/or add-ins like the Microsoft Excel Analysis ToolPak, BWStat has been developed using an exclusively formula-based approach. This results in a tool that contains no macros, but is relatively large (3.7 MB in its most compressed form as a Microsoft Excel 2010 .xlsb file).

What originally started as a British-Dutch cooperation in 2011, has grown in the meanwhile to a more internationally oriented group of specialists promoting this sampling strategy of which the main idea is presented in Figure 1. The international character is reflected in BWStat itself: version 2.1 is available in English, Dutch, French, German and Spanish. The language can easily be changed using a drop-down menu (Figure 2). After entry of some basic measurement parameters (Figure 2) and entry of the data (Figure 3), the conclusions are immediately available (Figure 4).

BWStat can be considered as a free, fast, safe and easy tool to facilitate implementation of the guidance, without having to install standalone software or add-ins or to enable spreadsheet macros. Thanks to its multi-lingual interface, it can be used by occupational hygienists and skilled exposure assessors all over the world.

Figure 1: Flowchart illustrating the five steps of the strategy. Form Similarly Exposed Groups (SEGs). Take 3 samples to eliminate groups that obviously comply or fail. If necessary, take at least 6 more samples and decide on group compliance. If compliant, perform ANOVA and BW-test to assess between-worker differences and test individual compliance when needed.

English	
Cotton dust	mg/m ³
1,70	mg/m ³
0,16	mg/m ³
0,04	mg/m ³

Figure 2: Start and Manual Tab. Enter basic analysis parameters here. From top to bottom: choose your language, enter the substance name and measurement unit (text data). The input of an OEL and a limit of quantification (LoQ) are required, a limit of detection (LoD) is optional (numerical data).

OEL	1,7	worker1	worker2	worker3	worker4
Date1	Mon	0,16	0,51	0,18	
Date2	Tue	0,38	0,60		
Date3	Wed	0,20	0,35		
Date4	Thur	0,44	0,70	0,65	
Date5					2,00

Figure 3: Data Tab. In the data entry module of BWStat, up to 50 worker names and 50 dates (maximum 2500 data points) can be entered or their values pasted from another data matrix. Conditional formatting gives visual support in providing all necessary information.

Stage 0: Screening test (Section 3.3)	
Are any of the samples >= 0,1 OEL?	Yes, see stage 1
Are any of the samples >= 1,0 OEL?	No, all samples are below the OEL

Stage 1: Group compliance test (Section 3.4)	
UTL95%,70%	1,10 < OEL 1,7 mg/m ³
Does the group comply with the OEL?	Yes, the group is in compliance with the OEL. Now check if between-worker differences are important (Section 3.5). See stage 2.

Stage 2: Apply ANOVA and if necessary Stage 3 (Section 3.5)	
P(ANOVA)	0,25 > p criterium 0,05
P(B&W)	No important differences between the workers. Individual compliance test not needed.
P(B&W)	18,42% < ad-hoc criterium 20%
P(B&W)	No important differences between the workers. Individual compliance test not needed.

Stage 3: Individual compliance test (Section 3.6)	
Probability that an individual worker has an exposure 95%-tile > OEL?	0,17% < ad hoc criterium 20%
Is the probability, that an individual workers' exposure 95%-tile > OEL, >= 20%?	No, routine monitoring (reassessment) (Section 3.8)

Figure 4: Report Conclusions Tab. The different conclusions which are to be drawn when the flowchart (Figure 1) is followed are presented in a logical order and colored or shaded where appropriate.

Figure 5: Graphs Tab. Modified boxplots (a.), ideal lognormal distributions (b.) and lognormal probability plots (c.) are included for graphical inspection of the data (between- and within-worker variability and fit of the lognormal model).

Group	AM	ASD	GM	GSD	Shapiro-Wilk	Shapiro-WilkC	UC95%,70%	UTL95%,70%	GM(Intercept)	GSD(Intercept)	UTL(Intercept)	number > OEL	Lognormal	Compliance,70%	Compliance,95%	df (number - 1)					
Greg (lowest GM)	0,42	0,20	0,37	1,73	0,90	0,84	2,80	2,01	1,10	0,37	1,76	2,70	2,01	1,14	0	1	1	9	1	8	
Joe (highest GM)	0,30	0,14	0,27	1,63	0,89	0,75	3,75	2,45	0,90	0,26	1,77	3,27	2,45	1,07	0	1	1	2	1	1	1
Chloe	0,54	0,15	0,52	1,35	0,95	0,75	3,96	2,45	1,09	0,52	1,39	3,62	2,45	1,16	0	1	1	2	1	1	1

Figure 6: Report Individuals Tab. When between-worker differences are important, one may be interested in knowing individual workers' parameters. Calculated parameters, regression estimators and a summary are available in this report.

A picture is worth a thousand words.

Whereas the guidance is very detailed on the calculations that are needed to evaluate group and individual compliance, it does not make any recommendations for visualization of group or individual exposure measurements. The authors however believe that some graphical exploratory data analysis preceding the formal data analysis may be very helpful. To avoid BWStat users having to pull their data through other tools for graphical inspection, modified boxplots and ideal lognormal and lognormal probability plots were also implemented in BWStat v2.1.

Modified boxplots are useful for inspecting between- and within-worker variability as well as for the identification of potential outliers (Figure 5a). The ideal lognormal distribution of a selected worker of choice can be compared with those of the group and the individuals with lowest and highest calculated geometric means (Figure 5b), and the fit of the lognormal model for the data can be judged using the corresponding lognormal probability plots (Figure 5c).

Introducing Regression on Order Statistics as an alternative for simple substitution of <LoQ results.

Many occupational hygiene datasets contain censored data and the guidance refers to third-party software to deal with them, which might cause unnecessary difficulty. Therefore BWStat offers its users, as an alternative to the simple but non-optimal substitution approach suggested in the guidance, the choice to use Regression on Order Statistics (ROS). In this way, even with censored data, all the required parameters needed in the flowchart can be calculated, even if 50% of the values are <LoQ. The by this choice affected calculated arithmetic and geometric means and standard deviations (AM, ASD, GM and GSD), as well as the Shapiro-Wilk statistic to assess lognormality and the Upper Tolerance Limit (UTL) to assess exceedance, are for this purpose displayed in a separate report (Figure 6, left). Moreover, unaffected regression estimators of GM, GSD and UTL using only the values >LoQ, are also calculated (Figure 6, middle). Finally, a summary on lognormality and compliance is displayed for the group as well as for the different individuals (Figure 6, right).

Conclusions

BWStat is a very convenient and visual tool that supports occupational hygienists and other assessors in adopting the British-Dutch guidance on sampling strategy. Moreover, the tool brings in several other basic exploratory and formal statistical data analysis methods as well as some ideas for future updates of the guidance.

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