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Published in:
Annals of Occupational Hygiene

DOI:
10.1093/annhyg/mev027

Published: 2015-01-01

Comparison and evaluation of multiple users' usage of the exposure and risk tool: Stoffenmanager 5.1

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Annals of Occupational Hygiene

Running title: Outcomes for multiple users of Stoffenmanager

Number of words: 6371

Number of pages: 18

Number of characters: 33244

Number of tables: 7

Number of figures: 2

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Abstract

Stoffenmanager is an exposure and risk assessment tool that has a control banding part, with risk bands as outcome, and a quantitative exposure assessment part, with the 90th percentile of the predicted exposure as a default outcome. The main aim of the study was to investigate whether multiple users of Stoffenmanager came to the same result when modelling the same scenarios. Other aims were to investigate the differences between outcomes of the control banding part with the measured risk quota and to evaluate the conservatism of the tool by testing whether the 90th percentiles are above the measured median exposures. We investigated airborne exposures at companies in 4 different types of industry: wood, printing, metal foundry, and spray painting. Three scenarios were modelled and measured, when possible, at each company. When modelled, 13 users visited each company on the same occasion creating individual assessments. Consensus assessments were also modelled for each scenario by 6 occupational hygienists. The multiple users' outcomes were often spread over 2 risk bands in the control banding part, and the differences in the quantitative exposure outcomes for the highest and lowest assessments per scenario varied between a factor 2 and 100. Four parameters were difficult for the users to assess and had a large impact on the outcome: type of task, breathing zone, personal protection and control measures. Only 2 scenarios had a higher measured risk quota than predicted by the control banding part, also 2 scenarios had slightly higher measured median exposure value than modelled consensus in the quantitative exposure assessment part. Hence, the variability between users was large but the model performed well.

Key words: exposure assessment, risk assessment, exposure modelling, occupational exposure, REACH

Introduction

Stoffenmanager is a web-based tool originally developed for small and medium-sized enterprises to facilitate risk assessment of chemical exposure in the workplace (Marquart et al. 2008). The tool originally had a qualitative control banding module that rated risks as low, medium, or high. Later, a quantitative part was developed to predict exposures as mg/m^3 (Tielemans et al. 2008), which was validated and recalibrated into today's version 5.1 (Schinkel et al. 2010).

Modern control banding strategies were developed in the COSHH (Control Of Substances Hazardous to Health Regulations) essentials programme in the 1990s. (Zalk and Nelson 2008). Under this programme a tool was developed that takes into account both hazards and potential exposures. The tool, developed for small and medium-sized enterprises, recommended controls based on the risk assessment. As in COSHH essentials, the hazard classification in Stoffenmanager is based principally on available risk phrases, but its exposure assessment is more advanced and based on an algorithm by Cherrie et al. (1996) and Cherrie and Schneider (1999). As the number of chemicals increased faster than occupational exposure limits (OELs) could be established to assess their risks, the need for control banding tools also increased (Zalk and Nelson, 2008). A control banding tool that prioritises risk is especially useful for small and medium-sized enterprises that do not have the resources to consult an expert in chemical risk assessment.

Although OELs are available for some chemicals, small and medium-sized enterprises may not have sufficient resources to measure exposures, and companies that do have the resources to measure exposures need to focus them on identified problem areas. The control banding part can be used to identify those areas. Models such as the Stoffenmanager's quantitative part may also be used to estimate and predict exposures in compliance with the REACH legislation, in which modelled exposures are compared with DNEL (derived no effect level) levels for safe use (ECHA 2012). Because one purpose of such tool is to select the right level of control, and under-prescription of control can lead to serious injury, the tools over-predict the exposure to ensure the security of the outcomes (Zalk and Nelson 2008). Hence, the models are conservative. Stoffenmanager gives the 90th percentile as a default conservative outcome.

Models that predict risks and exposures need to be studied for validity and between-user reliability. Validation studies of the quantitative exposure part of Stoffenmanager (Koppisch et al. 2012; Schinkel et al. 2010) showed that it was sufficiently conservative; however, no study has evaluated the reliability of either the quantitative exposure part or the control banding part to explore whether and how the results vary when multiple users study the same scenarios.

Our main aim was to study whether multiple users of the Stoffenmanager came to the same result when assessing same scenarios. Between-user agreement of input parameters was also examined and compared with consensus. Other aims were to compare the modelled control banding outcomes with measured risk quota and to investigate whether the 90th percentiles of the consensus assessments in the quantitative exposure part were above the median measured exposures to evaluate the conservatism of the tool.

Material and methods

Study design

This study began with in-house training of 6 experienced occupational hygienists (OH) in using the Stoffenmanager 5.1, followed by visits in 4 different types of industries for practice, as shown in Figure 1. The OH had contact with the Stoffenmanager consortia to answer any unresolved questions. After this step, 8 safety engineers (SE) were trained by the OH in using the tool, and they in their turn trained 16 company representatives (CR). None of the 6 OH, 8 SE and 16 CR had any experience in using Stoffenmanager prior this study started. The OH had between 20 and 40 years' experience in chemical exposure assessment at workplaces and is certified according to the Swedish certification scheme. The SE had between 15 and 40 years' experience in risk assessment at workplaces, not focused towards chemical exposures, but with regular handling of these kinds of issues. The CR were responsible for the company's work environment but were not necessarily trained in occupational hygiene or chemical risk assessment. Stoffenmanager was used at 16 companies represented by the CR to study the design, relevance, and user-friendliness of the tool. This will be presented elsewhere. In this study we revisited the 4 companies and analysed results for the same 4 OH and 8 SE, using Stoffenmanager in for 11 exposure scenarios (3 from each type of industry except for 2 scenarios from metal foundry industry). Moreover, 1 CR from each company

where also attending the exercise. All 13 users visited each of the companies on the same occasion and assessed the best fit for each scenario. This generated 13 individual assessments for each of the 11 scenarios studied. After the tool was used at the 4 companies, repeated exposure measurements were performed for each scenario. When all data had been collected, a round-table meeting was held with all 6 OH and the 11 different scenarios at the companies were reassessed and consensus were reached using both the control banding part and the quantitative exposure part of Stoffenmanager. In this article we present only the results generated by multiple users using Stoffenmanager at the companies, the consensus assessments, and the measured exposures.

Stoffenmanager 5.1

The Stoffenmanager 5.1 predicts airborne exposure using both a control banding part with a priority ranking system and a quantitative exposure assessment part.

The control banding part is based on COSHH Essentials (Marquart et al. 2008) and on the exposure model published by Cherrie et al. (1996) and further developed by Cherrie and Schneider (1999). The control banding part can be further divided into hazard classification and exposure classification. The hazard classification is based only on the risk phrases (R-phrases) or H-statement (according to CLP legislation) from safety data sheets (Marquart et al. 2008). Hazard classifications of chemicals are ranked by letter from A (most harmless) to E (most harmful). The exposure classification is based on how the chemical product is handled, and requires information about the product, process, and workplace as well as the chemical's vapour pressure (for a liquid) or dustiness (for a solid). The exact input parameters are presented elsewhere (Marquart et al. 2008). The exposure classification ranges from 1 (lowest) to 4 (highest). The hazard and exposure classification for each chemical are then combined to create prioritisation numbers, to show the order in which the scenarios should be prioritised for controls (Marquart et al. 2008).

In the quantitative exposure part the input parameters are mostly the same as in the control banding part, but vapour pressures for the components of the liquids are also needed instead of the vapour pressure for the whole product which is needed in the control banding part. The result from the quantitative exposure part is presented as the 90^{th} percentile of the predicted exposure in mg/m^3 (Tielemans et al. 2008).

The exposure algorithm used in Stoffenmanager, based on an equation and a system of scores, differs slightly between the control banding and the quantitative exposure parts in that the duration and frequency of the exposure apply only in the control banding part. The primary outcome of the quantitative exposure model is scores calibrated against measured exposures, giving a quantitative exposure value. The model takes into account both near- and far-field exposure, background exposure, reduction of transmission, and immission (Tielemans et al. 2008). Near-field exposure occurs when the worker's head is within 1 m of the source, and far-field exposure when the head is more than 1 m from the exposure source. Both near- and far-field exposure may occur at the same time when more than one worker is involved in an equal scenario or when a period of evaporation occurs.

The intervals of the weighting factors of the scores have a range from 0 to 30 at most, as shown in Table 1. The default score is 1 for a specific exposure concentration; with scores above and below 1, exposure concentrations will increase and decrease respectively (Marquart et al. 2008).

The Stoffenmanager's domain of applicability is clearly stated (Stoffenmanager, 2014). We focused mainly on scenarios within that domain, but with the addition of 1 scenario outside the scope to test whether it would still be useful.

Types of industries and exposure scenarios

The study was performed in 4 different types of industry: wood, printing, metal foundry, and spray painting. The industries were chosen for their known airborne exposures and different exposure scenarios. 1 company in each type of industry was chosen and 11 scenarios were selected (Table 2).

Wood

The company manufactured doors and had about 350 employees. Inhalable dust was measured and assessed with the Stoffenmanager for 3 different scenarios: "inspection and sanding," "milling and drilling," and "feeding."

Inspection of outside doors and manual sanding (only when necessary to reduce minor flaws) was a last quality step in the process. Exposure arose from wood dust laying on the doors and created during the sanding. This scenario was enacted at least 4 full working days a week.

There was no far-field exposure, no control measures or personal protection were used, and the work room was large with general ventilation.

Mechanical milling and drilling created wood dust from shaping the doorframes on at least 4 full working days a week, with only far-field exposure. A fixed capturing hood was used and the work room was large with general ventilation. No personal protection was used.

In the feeding operation large wooden planks used for inside doors were fed by hand to a mechanical saw. Exposure in this scenario mainly arose from the wood dust laying on the planks on at least 4 full work days per week (both near- and far-field). No control measures or personal protection were used and the work room was large with general ventilation.

Printing

The company manufactured labels and stickers and had about 50 employees. Measurements and assessments with Stoffenmanager were performed for 3 scenarios: “printing with imaging oil”, “printing with Flexocure”, and “washing screen frames”.

Printing with imaging oil involved printing on Hewlett Packard Indigo machines with exposure when the machines were printing oil on papers. This scenario was enacted 5 full working days per week. Only far-field exposure occurred and the source was contained and performed in a large working room with general ventilation. No personal protection was used.

Printing with Flexocure on a flexography machine was performed at least 4 full working days a week. Only far-field exposure occurred and the source was contained and performed in a large work room with general ventilation. No personal protection was used.

Screen frames were washed with a detergent containing the agent of interest. The frames were about 50 cm^2. This scenario occurred for 1 to 30 minutes for 5 days a week. Both near- and far-field exposure occurred, no control measures or personal protection were used, and the work was carried out in a large work room with general ventilation.

Metal foundry

The company moulded different metal objects and had about 150 employees. Measurements and assessments with Stoffenmanager were performed for 2 scenarios: “core making” and

"sanding". The sanding scenario is outside the scope of Stoffenmanager, and the result will therefore be presented only in tables.

In core making, a core of about 0.3 to 1 m^3 was made by pouring sand mixed with furfuryl alcohol into a mould. This scenario was enacted for about 2 hours a day every day of the week. Only near-field exposure occurred, no control measures or personal protection were used, and the work was performed in a large work room with general ventilation.

Sanding was done to create a fine surface on propeller blades of about 2 m. The mechanical sanding created a dust of different metals, mostly copper. This scenario was performed throughout every work day. Only near-field exposure occurred, no control measures or personal protection were used, and the work room was a relatively small spraying booth. Results from the sanding scenario are presented in tables and in the supplementary material.

Spray painting

The company maintained the painted surfaces of rolling stock fleets and had about 5 employees. 3 scenarios were selected "painting chassis", "painting locomotives", and "mixing paint".

Chassis (10 × 3 × 1 m) were spray painted. This scenario was performed up to 2 hours every day of the week. Both near- and far-field exposure occurred, the work was performed in a spraying booth and this scenario was measured and modelled both with and without personal protection. The personal protection used was a half or full face powers air respirator TMP2 or 3, this varied depending on size and how the objects shape was.

Locomotives were also spray painted, and this scenario was performed for up to 2 hours once a week. Both near- and far-field exposure occurred, no control measures were used, and the work was performed in a spraying booth. The personal protection used was a half or full face powers air respirator TMP2 or 3 depending on size and shape of the objects.

Paint was mixed in approximately 20 litres at a time in a separated room. This scenario was performed for about 30 minutes once every 2 weeks. Both near- and far-field exposure occurred, no control measures or personal protection were used, and the work was performed in a smaller work room with general ventilation.

Collection of data for Stoffenmanager

Users were provided information regarding dustiness or volatility, R-phrases, concentrations of components, and dilution; hence these parameters could not vary in their assessments. Input parameter data for the scenarios (Table 1) were collected by the users on visits to the workplaces where the scenarios were studied. All participants visited the workplaces on the same occasions. Each user handwrote all information needed for modelling on templates and these data were later put into Stoffenmanager by an OH. In some cases participants modelled scenarios other than those intended; when this occurred, the wrong scenarios were excluded from the study. This was especially the case in the scenario "printing with imaging oil"; only three users modelled the chosen scenario. The others modelled a scenario in which the oil in the machine was refilled. Also, in the control banding part, R-phrases were collected from safety data sheets. Because wood dust does not have R-phrases, even though it has some hazardous properties (Jacobsen et al. 2010) the R-phrases were set to R-36/37/38, which means irritating to eyes, skin, and the respiratory system.

Exposure measurements

Exposure measurements for the chosen scenarios were measured on 3 occasions in order to include some variation in exposure. The samples were taken on different days with intervals of at least one week. Sampling was performed in the breathing zone of the workers, outside protection (if any) and only during the specific tasks of interest. If the tasks were done during a short time period but multiple times a day, the measurements were taken throughout the day and the total time for the tasks was calculated. In one case the measured exposure was below the detection limit, so half that limit was used as a value. More details regarding the sampling and the analytical methods are described in the supplementary material.

Data evaluation

We used both parts of the Stoffenmanager, control banding and quantitative exposure. In both parts 13 users modelled the same scenarios and 6 OH provided consensus assessments (to be used as reference). For each scenario we have repeated measurements that were used in the data evaluation on both parts of the Stoffenmanager.

In the control banding part, the outcomes from the users were risk classes. Two different evaluations were made: (1) the risk classes from the 13 users were compared with consensus, and (2) the risk classes were compared with a traditional approach using OELs. For comparison with the OELs we used a classification suggested by the UK Health and Safety Executive (HSE, 2006). We divided the measured median exposure with a Swedish OEL (where available) for the chemical in question. This quota (measured risk quota) was used as a risk measure assessed without the tool. If the quotient was below 0.3 the risk was considered to be low and if the quotient was above 1.0 the risk was considered to be high.

In the quantitative exposure part, the outcomes used were the default 90th percentiles of the modelled exposure in mg/m^3. Four different evaluations were made: (1) evaluation of the conservatism of the tool by comparing the modelled consensuses with the measured median exposures, and also comparing the ranges of the multiple users' modelled outcomes with the ranges of the measured exposures; (2) evaluation of the variability of the multiple users' outcomes by calculating quotas between the highest and lowest outcomes and for the 75th and 25th percentiles for each scenario; (3) evaluation of the choices of input parameters from the multiple users compared with the modelled consensus by calculating the percentage of users' agreements with consensus for each input parameter; and (4) evaluation of which input parameters had the greatest impacts on the outcomes by studying the highest and lowest outcomes from the multiple users' modelled outcomes for every scenario by changing one input parameter at the time and study how the outcomes changes.

Results

Control banding

The results of the control banding part can be seen in Table 3.

In the wood industry the outcomes of the scenario "inspection and sanding" were mostly in the medium risk class, as was consensus. However, the measured risk quota was low. The outcomes of the scenario "milling and drilling" were mostly in the low risk class (with some in the medium risk class) and consensus was also in the low risk class, as was the measured risk quota. The big differences in outcomes for the "milling and drilling" scenario were due to differences in answers about the type of the task, the kind of controls used, and whether it was

shaping of material. The outcomes for the “feeding” scenario were mostly in the medium risk class, with two in the high risk class, while consensus was in the high risk class and the measured risk quota was low. The differences in outcomes for the “feeding” scenario were due to different answers regarding type of task and if the task was performed in the breathing zone or not.

In the printing industry all three outcomes of the scenario “printing with imaging oil”, as well as consensus, were in the low risk class, as was the measured risk quota. In the second scenario “printing with Flexocure,” the outcomes were distributed between the low and medium risk classes, but consensus was in the low risk class. No Swedish OEL exists for dipropylene-glycol-diacrylate, but AIHA has limits for other acrylates which we used for comparison (AIHA, 2011). This measured risk quota resulted in a very low risk. The input parameters of the multiple users’ modelled outcomes that differed in this scenario were the type of task, whether or not the source of exposure was in the breathing zone of the worker, and which controls were used. In the third scenario “washing of screen frames,” all 13 users’ modelled outcomes were in the medium risk class, as was the consensus assessment, while the measured risk quota was very low.

In the metal foundry the outcomes of the scenario “core making” were in all cases except one in the low risk class, as was the consensus assessment, but the measured risk quota was high.

In the spray painting industry the outcomes of the scenario “painting chassis – with protection” ranged between the low and medium risk classes, with most outcomes in the medium risk class. Without personal protection the outcomes were all in the medium risk class, except for one in the low risk class. Consensus in both cases was in the medium risk class. In the painting chassis scenario, the measured risk quota was low when using protection and medium without protection. In the second scenario, “painting locomotives – with protection” the outcomes from the multiple users and consensus were all in the low risk class. However, in the “painting locomotive” scenario the multiple users’ modelled outcomes were mostly in the low risk class, but with 5 outcomes in the medium risk class. Consensus was in the medium risk class, as was the measured risk quota. The differences in outcomes for this scenario were due to differences in answers regarding type of task and frequency. In the “mixing paint” scenario the multiple users’ modelled outcomes were all in the low risk class

except one in the medium risk class. The consensus outcome was in the low risk class, as was the measured risk quota.

Quantitative exposure

The results of the quantitative exposure part are shown in Table 4. As there were no obvious differences in outcome due to users' experience the result will be presented as a total and not sorted by users' backgrounds.

In the wood industry the consensus exposures for all three scenarios were well above the measured median exposures. The ranges in the multiple users' outcomes were above the measured range in 2 of 3 scenarios, with a small overlap in the last one.

In the printing industry the consensus outcomes for 2 of 3 scenarios were well above measured median exposures. For the scenario, "printing with imaging oil," the measured median exposure was slightly above the modelled consensus. The ranges of the multiple users' outcomes overlapped the measured exposure range in 1 scenario, but in 2 scenarios were higher than the measured exposure range.

In the metal foundry industry the outcome of the consensus assessment was above the measured median exposure. The range of the multiple users' outcomes overlapped the measured exposure range.

In the spray painting industry the outcome of the consensus assessments were well above the measured median exposure in 3 of 4 scenarios. 1 scenario, painting chassis without personal protection, had a lower modelled consensus than measured median exposure. The ranges of the users' outcomes were above the measured exposure range in three of four scenarios, but for painting chassis without protection the modelled exposure range overlapped the measured exposure range.

Variability in multiple users assessments

The differences between the users' modelled outcomes in the quantitative exposure part are large, as shown in Figure 2. The factors between lowest and highest outcomes in every scenario and the factors between the 25th and 75th percentiles in every scenario are presented in Table 5.

In the wood industry the ranges were widest in the feeding scenario with a factor 64. The factor between the 75th and 25th percentiles were only 2,3. Hence, at least half of the multiple users' modelled outcomes were quite similar. In the other two scenarios the factors between the 75th and 25th percentile were near half of the factor between the highest and lowest outcomes respectively.

In the printing industry the ranges between highest and lowest outcomes were in general lower than for the other types of industry. The scenario "printing with Flexocure" had the widest range between highest and lowest outcome, with a factor 12.

In the metal foundry industry the range between highest and lowest outcomes in the "core making" scenario was a factor 52 also the range between the 75th and 25th percentile were quit high with a factor 5,7.

In the spray painting industry the range between highest and lowest outcomes were in general high. The largest differences were in the "painting locomotive – w.p." scenario with a factor 162. Also, "painting locomotive" had a large difference with a factor 97. In the painting chassis scenarios the ranges for the highest and lowest outcomes were a factor 45 but there were no range between the 75th and 25th percentile. Hence, most users modelled similar and only a few users modelled the extreme outcomes.

Analysis of input parameters; users' choices and its effects for the outcomes

The differences were large in the outcomes because some of the input parameters have shown more variability in the answers than others. In Table 6 the different input parameters of Stoffenmanager is presented with the number of choices and how many users that had chosen the same input parameter as consensus. The overall result showed that some parameters are less agreeable with consensus. For instance type of task only had 49 % agreeable with consensus. Personal protection and control measures also have low percentage agreement with consensus with a percentage of 39 and 74 respectively.

Which choice of input parameter that had the greatest impact on the outcomes is presented in Table 7. The result shows that the type of task, breathing zone, ventilation and control measures had greatest impact on the outcomes.

Discussion

In this study we evaluated the Stoffenmanager tool for assessing risk and exposure with the participation of 13 independent users who simultaneously visited the companies and studied the various scenarios. To our knowledge this has not been done before, although one reliability study has been done for the more advanced exposure tool; The Advanced REACH Tool (Schinkel et al. 2014). A strength of this study was the simultaneous visits to the actual work places, but an accompanying weakness was our inability during the visits to give assessors exact instructions about the scenarios (because if we had, we may have reduced differences in the assessments). This resulted in some of the users assessing a closely related scenario, but not the one chosen for the study. Another limitation is that the users were given information about dustiness and volatility, if this also would have been assessed the true variation would probably been even higher.

For each studied scenario we also performed exposure measurements on three different occasions to get an idea of the variation in exposure. Of course this may not be enough to get a real picture of the variation and the small dataset will of course influence the interpretability of the study. More measurements would be desirable, but measurements are costly and time consuming. We endeavoured to take as many measurements as we could give with available resources.

Six experienced OH came to a consensus agreement for each scenario, which was much more difficult than anticipated; it took about a whole day each to agree on assessments for the 11 scenarios.

For the comparison of the control banding part and the achieved risk assessments with traditional occupational hygiene methods we used a classification suggested by HSE (HSE, 2006). Comparing risk assessments in the Stoffenmanager with the measured risk quota is obviously problematic. In the absence of more directly comparable models, we chose to use this simple approach to provide the best available, if not ideal, picture of the performed risk assessment of Stoffenmanager

Control banding

The main difference between the control banding part and the quantitative exposure part in the Stoffenmanager is that the control banding part has not only an exposure classification, but also a hazard classification based on the R-phrases. This may be a weakness: if the agent

in question has some hazard properties but no R-phrases, the risk assessment may predict a risk lower than the actual case. When hazard properties, but not R-phrases, are known the hazard properties can be converted to R-phrases, as we did for the wood industry. This has special importance when choosing the input parameter "shaping of material" for use in the Stoffenmanager. For this parameter only two materials can be chosen: wood or stone. These materials are pre-programmed in the tool and will automatically be placed in hazard class A. In this study, the risks in the wood industry in the first two scenarios the measured risk quota were low and in the feeding scenario it was medium, but in the consensus outcomes all three risk classes were represented, reflecting the different types of tasks of wood in the scenarios. In the "inspection and sanding" scenario the consensus output was in the medium risk class and the measured risk quota was low. We cannot find a reasonable explanation for this. In the scenario "feeding" no shaping of the material occurred and our own selected R-phrases was used, resulting in a much higher risk indicated by the control banding part than by the measured risk quota.

An important aspect to consider in the differences for the risk assessments between the Stoffenmanager and the traditional way of assessing risk is the inherent differences of R-phrases and OELs (that the measured risk quota is based on). For the scenario "washing screen frames," all modelled outcomes were in the medium risk class, but when the risk was assessed with measurements and OELs it was low. This may be explained by the fact that the OEL for naphtha is relatively high (300 mg/m^3), whilst the R-phrases for petroleum naphtha are classified as hazard class C. A similar problem occurred in the scenario "core making": the OEL for furfuryl alcohol from the American Conference of Governmental Industrial Hygienists (ACGIH) in US is 20 mg/m^3, which makes the risk assessed with measurements very high because the measured median exposure was 40 mg/m^3. However, the R-phrases for furfuryl alcohol are in hazard class B, which is quite low. This in turn makes the risk assessed in Stoffenmanager low.

Quantitative exposure

The consensus outcomes in the quantitative exposure assessment part in the scenarios "printing with imaging oil" and "painting chassis without protection" are lower than the measured median exposures. However, both consensus assessments of these scenarios are in the same order of magnitude as the measured median exposure. For the scenario "painting chassis with protection" the consensus assessment is well above the measured median

exposure. This indicates that the added protection does protect more than the tool estimate. As shown in Table 4, the reduction of exposure with personal protection in the consensus assessment was about 90 %. The measured median exposure indicates that the reduction was about 99.9 %. However, only one measurement was taken using the personal protective equipment. Moreover, when comparing the outcomes of the multiple users' assessments with measured range of exposure for the 11 scenarios, 7 scenarios had their lowest outcome higher than the highest measured exposure. This shows that, even though the large variations in assessed exposure most of the performed assessments were higher than the highest measured exposure.

Differences in multiple users outcomes

When multiple users modelled the same scenarios the variations were high, which is in concordance with the findings from the reliability for ART (Schinkel et al. 2014). As shown in Table 6, the six input parameters with lowest concordance with consensus were personal protection, material shaping, type of task, inspection and maintenance of machines, control measures and breathing zone., . In Table 7, the input parameters that had greatest impact on the outcome when comparing the highest and lowest outcome in each scenario shows that type of task, breathing zone, ventilation and control measures had the highest impacts. The combined results of Tables 6 and 7 show the input parameters most important to understand to reduce variations and therefore type of task, breathing zone, control measures and personal protections will be discussed further.

The different answers regarding the types of task were generally close to each other, but as seen in Table 1 the weighting factors for the task have a wide spread (0–10 or 1–30), which means that outcomes would vary significantly if different type of tasks were chosen. The range of the multiple users' outcomes were widest in the "feeding" scenario, as shown in the boxplot in Figure 2; this may be explained by the fact that a scenario may sometimes be difficult to identify when two different tasks are performed during the same scenario. In this case some users modelled the exposure from the mechanical saw, because they interpreted this as the worst case source of exposure, when in fact the scenario was meant to illustrate exposure from the wooden planks being fed to the saw. The same problem occurred in the scenario "inspection and sanding," in which some users assessed only the inspection and others the sanding. The worker did these tasks simultaneously as needed.

There are only two answers to choose between regarding the breathing zone, but it has a large impact on the outcome given the equation used in the Stoffenmanager (Tielemans et al. 2008). For example, in the printing industry the outcomes in the control banding part of the scenario, “printing with Flexocure” had 4 outcomes in the low risk class and in the medium risk class, mainly due to different answers regarding the breathing zone. It may be difficult to decide whether the source of the exposure was in the breathing zone or not, especially if an exposure source is sometimes in the breathing zone and sometimes not in the same scenario. In the “printing with Flexocure” scenario, in which stickers and labels are printed, workers may be assumed to be sometimes in the breathing zone (to inspect) and sometimes not. It remains unclear how long a worker should be near the exposure source in the modelling of this scenario to count it as time in the breathing zone.

More choices need to be decided in the area of personal protection which has widely spread weighting factors (0.05–1). Choice of personal protection has a large impact on outcomes because of the equation. In the scenario “painting chassis without protection” the consensus outcomes from the control banding part were in the medium risk class, but the measured risk quota were high, just above 1. When protection was used, only half of the assessments moved from the medium to the low risk class. This is explained by the fact that when modelling without protection some outcomes were already near the border to the low class; when modelling with protection, only those assessments moved to the low risk class and the others remained in the medium class. This gives a somewhat lower reduction of the exposure than may actually be the case.

Control measures also have a higher number of choices, which because of its widely spread of weighting factors has a high impact on the outcome. The input parameters vary in the multiple users’ assessments from no control measures at the source to containment of the source. Local exhaust ventilation (LEV) was also difficult to assess, as its effectiveness may be depend upon its placement in the working room.

Answers may also differ if the work task performed falls between or outside the defined choices of the input parameters. For example, in the scenario “core making” the procedure of handling is complex because the furfuryl alcohol is mixed with sand before it is poured into the mould. There are no suitable ways to model this scenario in Stoffenmanager, which may

be one explanation of the low risk outcomes in Stoffenmanager when the measured risk quota was high.

Both worst case and best fit assessments may be modelled and the outcomes will differ, hence the motive of doing risk assessments plays a dependent role in the outcomes. However, in this study the assessors were told to assess the best fit. It has been shown for a similar tool; ART that the variation can be reduced with more training before use. The authors also believed that improvements of the guidance sheets and using consensus assessments could reduce some variation (Schinkel et al. 2014). One further improvement could be adding PIMEX videos together with typically exposure assessments made with the tool in the guidance sheets (Rosén et al. 2005).

Conclusions

The control banding part of Stoffenmanager gives a good overview of the risks in the different scenarios. Of our 11 scenarios, 2 showed lower risk and 4 showed higher risks by the Stoffenmanager than by the measured risk quota. The impact of the numerical value of the OEL and the applied hazard score needs to be further elucidated.

On the quantitative exposure part only two modelled consensus were slightly lower than the measured median exposures, which indicate that the model is as conservative as wanted. However, the number of scenarios studied was low.

Variations between multiple users modelling the same scenarios were high. The input parameters with the highest impact on the outcomes and that differed between the various users were; type of task, breathing zone, control measures, and personal protection. These input parameters may therefore need more thought than others.

Acknowledgement

Financial support for this work was obtained from the Swedish Research Council for Health, Working Life and Welfare: Forte. The authors also thank Ms. Karin Wilander for her valuable help with data management. Many thanks also to the participating companies and safety engineers for their very important contributions to this study.

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Figure 1 Outline of the study design

Figure 2. Distribution of quantitative results from multiple users' assessments of 11 scenarios. Scenarios; 1: Inspection and sanding, 2: Milling and drilling, 3: Feeding, 4: Printing with imaging oil, 5: Printing with Flexocure, 6: Wash of screen frame, 7: Core making, 8a: Painting chassis w.p, 8b: Painting chassis, 9: Painting locomotive and 10: Mixing paint. The box shows the 25th, median and 75th percentile and the bars min and max values. Circles represent outliers (1.5 box-lengths from the box); asterisk are extreme points >3 box-lengths from the box. (Pallant, 2007). w.p. = with protection.

Figure 1.

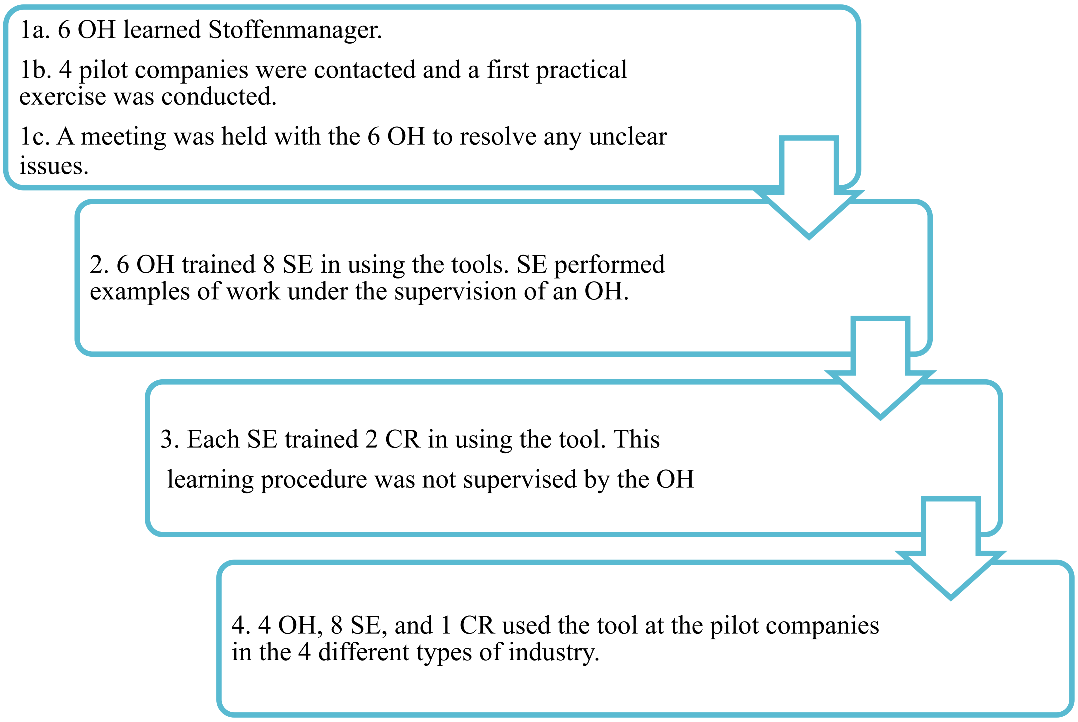
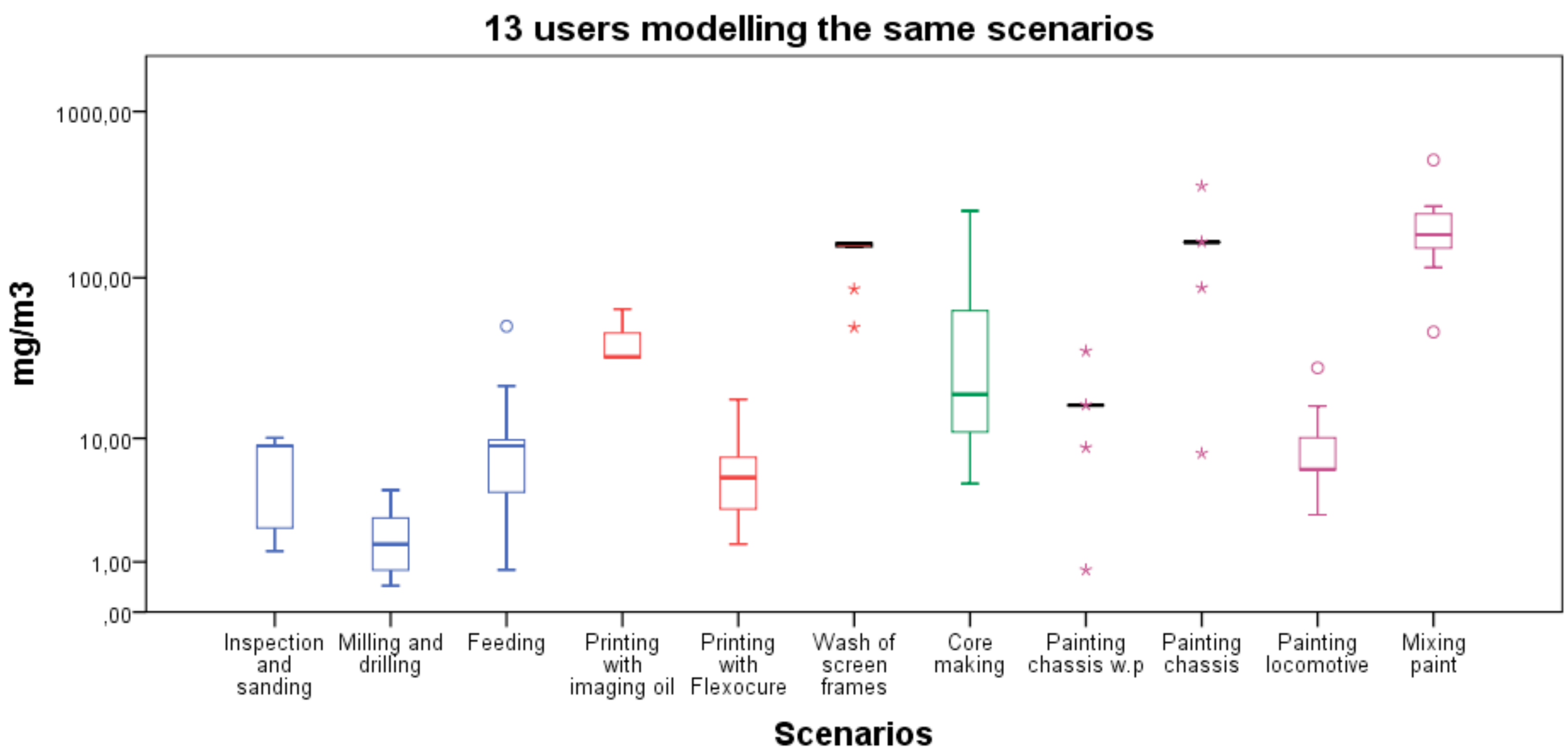

1a. 6 OH learned Stoffenmanager.
1b. 4 pilot companies were contacted and a first practical exercise was conducted.
1c. A meeting was held with the 6 OH to resolve any unclear issues.
2. 6 OH trained 8 SE in using the tools. SE performed examples of work under the supervision of an OH.
3. Each SE trained 2 CR in using the tool. This learning procedure was not supervised by the OH
4. 4 OH, 8 SE, and 1 CR used the tool at the pilot companies in the 4 different types of industry.

Figure 2.



Circles represent outliers (1.5 box-lengths from the box); asterisk are extreme points >3 box-lengths from the box. (Pallant, 2007). w.p. = with protection.

Table 1. Input parameters for Stoffenmanager with number of choices and distribution of score intervals.

Input parameters	Number of choices	Weighting factor intervals
Liquid		
- Type of task	8	0–10 (b)
solid		
- Does it concern removing or cutting of material?	2	Yes/No (a)
If yes		
- Type of task		
- Wood	6	1–30 (b)
- Stone	4	1–30 (b)
If no		
- Type of task	8	0–30 (b)
Duration of task	4	0.06–1 (a)
Frequency	6	0.01–1 (a)
Breathing zone	2	Yes/No
Multiple employees doing the same task	2	Near field/Far-field
Task followed by evaporation, drying, or curing	2	Yes/No
Personal protection	8/14[c]	0.05–1 (a)
Volume of working room	4	0.1–10 (a)
Type of ventilation	4	0.1–10 (a)
Cleaning of working room	2	0–0.03 (a)
Inspections and maintenance of machines	2	0–0.03 (a)
Control measures	5	0.03–1 (a)
Working in a cabin	3	0.03–1 (a)

a: (Marquart et al. 2008)

b: (Schinkel et al. 2010)

[c]: 8 is for liquids and 14 is for dusts

Table 2. Industries, scenarios, agents, and methods of exposure measurement.

Industry	Scenario	Agent	Method
Wood	Inspection and sanding	Wood dust	Inhalable dust[1]
	Milling and drilling	Wood dust	Inhalable dust
	Feeding	Wood dust	Inhalable dust
Printing	Printing with Oil	Petroleum hydrocarbon	Charcoal tubes
	Printing with FLexocure	Dipropylene diacrylate	XAD2-tubes with dislycol glass fibre filter
	Wash of screen frame	Petroleum naphtha	Charcoal tubes
Metal foundry	Core making	Furfuryl alcohol	Anasorb CSC SKC
	Sanding[2]	Cupper dust	Inhalable dust
Spray painting	Painting chassie	Xylene	Anasorb CSC SKC
	Painting locomotive	Hexamethylene diisocyanate	Polypropylene tube with glass fiber filter and di-n-butylamin (DBA)
	Paint mixing	Butyl acetate	Anasorb CSC SKC

[1] Gravimetric analysis.

[2]This scenario is outside the scope of Stoffenmanager and will therefore only be presented in tables. Other information is in the supplementary material.

Table 3. Stoffenmanagers' control banding outcomes from 13 users with exposures (mg/m^3) shown in relation to Swedish OELs.

Industry	Scenario	Agent	Multiple users				Consensus			Measured exposure				Measured/OEL		
			Hazard class[a]	Risk class			Risk class							Risk class[e]		
				Low	Medium	High	Low	Medium	High	n[b]	Median	Range	OEL	Low	Medium	High
Wood	Inspection and sanding	Wood dust	A, C	1	10			1		3	0.48	0.35 – 0.59	2	0.24		
	Milling and drilling	Wood dust	A, C	8	5		1			3	0.44	0.34 – 0.53	2	0.22		
	Feeding	Wood dust	A, C		10	2			1	3	0.68	0.37 – 0.72	2		0.34	
Printing	Printing with imaging oil	Petroleum hydrocarbon	A	3			1			3	39	35–43	300	0.13		
	Printing with Flexocure	DPGDA	C	4	4		1			1	0.026	0.026	1[c]	0.026		
	Wash of screen frame	Petroleum naphtha	C		13			1		4	20	n.d. –50	300	0.067		
Foundry	Core making	Furfuryl alcohol	B	10	1		1			3	36	30–54	20			1,8
	Sanding	Cupper dust	A,D		4	5		1		2	2,6	0,7-4,6	1[d]			2,6
Spray painting	Painting Chassis (w.p.)	Xylene	B	4	8			1		1	0.45	0.45	221	0.0020		
	Painting Chassis	Xylene	B	1	11			1		4	213	113–363	221		0,96	
	Painting locomotive (w.p.)	HDI	C	11			1			-	-	-	-			
	Painting locomotive	HDI	C	7	5			1		8	0.013	0.0060-0.026	0,02		0,65	
	Mixing paint	Butyl acetate	A	11	1		1			2	8.9	4.5–13	500	0.018		

[a]: For hazard class; when chosing shaping of material it will automatically be A. If not chosing this the hazard class will be based on R-phrases.

[b]: Number of measurments

[c]There is no Swedish OEL for DPGDA, but AIHA have OELs for other acrylates; 1 mg/m^3

[d]: This OEL is for total dust of cupper

[e] The risk class is classed as low if the quota is lower than 0.3, as medium if the quota is between 0.3-1 and high if the quota is higher than 1.

The source of the swedish OELs: AFS 2011:18

DPGDA = dipropylenediglycolediacrylate

n.d. = not detected

w.p. = with protection

Table 4. Results of the quantitative exposure assessment part in Stoffenmanager with multiple users (N=13), consensus and the measured exposures (mg/m^3).

Industry	**Scenario**	**Agent**	**Stoffenmanager, multiple users**			**Stoffenmanager, consensus**	**Measured exposure**			
			90th percentile			90th percentile				
			Median	Mean	Range	Consensus	n	Median	Mean	Range
Wood	Inspection and sanding	Wood dust	8.9	6.9	1.3–10	8.9	3	0.48	0.47	0.35–0.59
	Milling and drilling	Wood dust	1.6	2.0	0.4–4.4	1.6	3	0.44	0.44	0.34–0.53
	Feeding	Wood dust	8.9	11	0.8–51	21	3	0.68	0.60	0.37–0.72
Printing	Printing with imaging oil	Petroleum hydrocarbon	33	43	32–65	32	3	39	39	35–43
	Printing with Flexocure	DPGDA	5.4	6.5	1.6–18	3.9	1	0.026	0.026	0.026
	Wash of screen frame	Petroleum naphtha	162	140	50–163	162	4	20	22	n.d.–50
Foundry	Core making	Furfuryl alcohol	19	48	4.9–253	63	3	36	40	30-54
	Sanding	Cupper dust	15,8	40	2,2-177,3	12,3	2	2,6	2,6	0,7-4,6
Spray painting	Painting chassis (w.p.)	Xylene	16	16	0.8–36	16	1	0.45	0.45	0.45
	Painting Chassis	Xylene	164	160	7.9–357	164	4	213	225	113–363
	Painting locomotive (w.p.)	HDI	0,62	0,63	0,01-1.62	0,62	-	-	-	-
	Painting locomotive	HDI	6.2	8.9	0.29–28	6.2	8	0.013	0.016	0.006–0.026
	Mixing paint	Butyl acetate	185.0	206	47–512	218	2	8.9	8.9	4.5–13

DPGDA = dipropylenediglycolediacrylate

n.d. = not detected

w.p. = with protection

Table 5. Variability of the quantitative modelling for the 13 users in the different scenarios.

Industry	Scenario	Agent	Multiple users	
			Quotas	
			Max/min	$75^{th}/25^{th}$ percentile
Wood	Inspection and sanding	Wood dust	7.6	4.1
	Milling and drilling	Wood dust	10	3.6
	Feeding	Wood dust	64	2.3
Printing	Printing with imagine oil	Petroleum hydrocarbon	2.0	2.0
	Printing with Flexocure	DPGDA	12	2.5
	Wash of screen frame	Petroleum naphtha	3.3	1.1
Foundry	Core making	Furfurylalcohol	52	5.7
Spray painting	Painting Chassis (w.p.)	Xylene	45	1.0
	Painting Chassis	Xylene	45	1.0
	Painting locomotive (w.p.)	HDI	162	2.6
	Painting locomotive	HDI	97	1.8
	Mixing paint	Butylacetate	10	1.6

w.p. = with protection

DPGDA = Dipropylenediglycolediacrylate

Table 6. The comparison between the multiple users' choice of input parameters and consensus input parameter.

Input parameter	Number of choices	Number of assessments	% of agreement with consensus
Does it involve shaping a material?	2	47	38
Type of task	8	126	49
Breathing zone	2	126	81
Task followed by evaporation, drying, or curing	2	94	91
Personal protection	8	23	39
Volume of working room	4	126	92
Type of ventilation	4	126	87
Cleaning of working room	2	126	87
Inspections and maintenance of machines	2	126	69
Control measures	5	126	74
Working in a cabin	3	126	100