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Assessing Solvent Exposure In Connecticut Auto Body Shops

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Abstract

Objective The objectives of this paper are to characterize solvent exposure on an individual basis by auto body shop tasks, establish if solvent concentrations fall below current regulatory standards, and to determine predictive factors for solvent exposure levels. Predictive factors being analyzed are: indoor temperature, outdoor temperature, indoor relative humidity, outdoor relative humidity, booth type, ventilation (bay door use and general exhaust use), paint type, and specific task.

Methods Data for this paper was obtained from The SPRAY (Survey of Painters and Repairers of Autobodies by Yale) study. All statistical analysis was performed in SAS. A log transformation was first applied on all the solvent concentrations to normalize the substantial skew in the distribution. Descriptive statistics were calculated. Regression models were created for each solvent and total solvent concentration. A bivariate model was first created for each solvent and predictor. Then stepwise regression (backwards elimination) was employed to create parsimonious models.

Results The solvents with the greatest maximum concentrations are acetone, toluene, and m&p xylene. Benzene had the lowest average (0.07 mg/m3) concentration and range (0-3.13 mg/m3). All of the samples fell below current regulatory limits with the exception of one toluene sample. With the exception of m&p xylene, task was a significant predictor variable for all solvents and total solvent concentrations. The tasks that produced the highest levels of solvent concentrations are: gun cleaning, spraying, and mixing.

Conclusion Most solvent concentrations in the SPRAY study fall well below regulatory standards. However, this is not an indicator of safety as many regulatory standards are outdated.

Future studies should explore the health effects of chronic exposure to permissible levels of solvents.

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Introduction

Health Effects of Solvents

Solvent exposure is known to cause toxicity to the nervous system, reproductive damage, liver and kidney damage, respiratory impairment, cancer, and dermatitis (OSHA Solvents, 2013). Millions of workers, including those in the automotive refinishing industry, are exposed to solvents on a daily basis (OSHA Solvents, 2013). OSHA has set solvent standards for General Industry, Shipyard Employment, and the Construction Industry (OSHA Solvents, 2013). Although auto body shop workers should use respirators, gloves, and other protective gear, the improper use or lack of gear and administrative factors can still leave the workers at risk for solvent exposure. Table 1 shows the health effects of solvents measured in this study, which are typically found in auto body shops.

Numerous studies have been conducted on the health effects of occupational exposure to organic solvents. A study by *Moen et al* (1990) utilized an exposure index that accounted for level and duration of solvent exposure in a study of 85 seamen. The index was used in a multivariate regression model that related exposure to effect. The study found that in terms of visual abstraction ability and memory span, the higher the exposure index, the lower the performance (negative correlation). In terms of more adverse health effects, studies have looked at the cancer incidence of individuals with long-term solvent exposure. A 1995 Scandinavian study analyzed the incidence of cancer and deaths among patients who went to 11 clinics for occupational medicine because of solvent exposure. In the cohort of 5,791 people (5,283 men and 508 women), there was a slightly elevated total cancer incidence as compared to the national incidence rates of cancer (*Berlin et al 1995*).

Solvent Exposure in Auto Body Shops

To date, there is limited literature on the assessment of solvent exposure in auto body shops. The majority of published literature estimates exposure through job history or self-reported estimates.

A 1984 study at the Environmental Studies Institute at Drexel University characterized the health hazards in a small automotive shop, with solvents as one of the hazards of interest. The paper focused on xylene, toluene, and benzene, measured as a PPM found by volume in the air. Investigators analyzed the solvent levels found in spray tasks in different conditions: spray booth fan on/off (for booth sprays), external door closed/open, and work bay area in summer/winter (for non-booth sprays). The study found that in the summer, there is no difference in exposures between the work bay and spray booths because all outside doors are open and floor fans are on. However, winter tasks in the work bay with closed external doors resulted in higher exposure levels, as expected. The study found that full shift TWAs are rarely exceeded, but STELs are often greatly exceeded (*Jayjock et al., 1984*).

A 1987 study assessing color vision loss among solvent exposed workers in a paint manufacturing plant measured solvent concentrations (TWA in mg/m^3) in the production department of the plant. The solvents analyzed were: acetone, MEK, toluene, xylene, styrene, MIBK, 2-ethanoxyl ethanol, and 2-ethanoxy ethanol acetate. Toluene emerged as the solvent with the greatest maximum TWA. The workers were classified into two categories of exposure:

moderately exposed and highly exposed. Specific job functions or tasks were not a part of the study (*Mergler et al., 1987*).

A 1992 Australian study of solvents in automotive body repair shops found that individual solvent exposures varied greatly. Toluene was found in most samples and was the most common contaminant. Solvent exposure was expressed as mg/m3. Toluene was 43.5 mg/m3 (range: 4-323), xylenes were 8.7 mg/m^3 (4-26 mg/m^3), acetone was 34.1 mg/m^3 (12-77 mg/m^3), butyl acetate was 11.7 mg/m^3 (2-23 mg/m^3), benzene was 1.0 mg/m^3 (1-1 mg/m^3), and ethyl acetate was 17 mg/m3 (only one sample detected EA). Total solvent exposure was 19% (total solvent exposure on a range of 1-99% of a combined Worksafe Australia exposure standard). One of the possible explanations that this study yielded a low exposure rate is that the solvent measurements were short term exposure samples rather than long-term time weighted averages. Task analysis was also conducted. Tasks were grouped into three categories: 1) Spraying acrylic paint in the open workshop or outside, 2) spraying two-pack paint inside a spray booth, or 3) Other- filling with putty, sanding, buffing, masking, cleaning spray guns. A mean composite exposure percentage was determined and spraying acrylics (outside of booth) had, by far, the highest exposure level. None of the exposures exceeded the Worksafe Australia combined exposure standard (*Winder et al.,1992*).

SPRAY Study

The SPRAY (Survey of Painters and Repairers of Autobodies by Yale) study started in 1997 to determine the effects of isocyanate exposure on workers in auto body shops, since isocyanates can cause or aggravate asthma. The study collected air samples for isocyanates from 37 Connecticut auto body shops. During the course of this study, measurements for other potentially harmful exposures were collected—including solvent exposure. The target analytes were: acetone, methyl ethyl ketone (MEK), benzene, ethyl acetate, methyl isobutyl ketone (MIBK), toluene, butyl acetate, ethyl benzene, m and p xylene, o xylene, styrene, 2-ethoxyethanol, and 2-methoxyethanol. The main source of organic solvents in the auto body shops are from bondo, whose main component is styrene. For paints, the most common components are xylene, toluene, butyl acetate, and MEK.

Four to six task based solvent samples were taken at each shop. Tasks sampled were: spraying paint in spray booths and outside spray booths (*spray*), area sample to characterize bystander effect near and far from a spray task (*near spray, far spray*), area sample to characterize bystander effect in the shop and office (*background*), mixing of paint (*mixing*), cleaning spray guns (*gun cleaning*), applying automotive repair filler (*bondo*), area sample to characterize bystander effect near a bondo application (*near bondo*), and wiping vehicles (*wiping*) (Woskie *et al.* 2003).

For spraying conducted in booths, the type of booth was noted. These include downdraft (air entering through the ceiling and exiting through the floor), semi downdraft (air entering through the ceiling and exiting through the door), and crossdraft (air coming in through the filters in the door and exiting through the back, but could be any lateral configuration). Prep station was also included as a booth type. A prep station is a curtained off area with an exhaust filtration system within a shop, where cars are prepped for painting and sometimes painted too (Sparer *et al.* 2004).

Weather variables (indoor temperature, outdoor temperature, indoor relative humidity, and outdoor relative humidity) were measured during each sample. Temperature is a possible factor in solvent exposure levels because it affects the rate of solubility and paint drying times. Relative humidity can also affect paint drying time, with humid weather producing the slowest dry times (Duffy, 2003). Ventilation variables included bay door (open or closed) and general exhaust (open or closed). Bay door is a large door that opens up the entire body shop area and the general exhaust are overhead exhausts in the shop area. Paint types included in the study are: base coat, clear coat, primer, sealer, and single stage (paint that does not require a clear coat for a glossy finish).

Sampling Method

Solvent exposure was measured for individual tasks with Thermal Desorption Tubes (TD) and/or Charcoal Tubes (C). TD air samples were collected using Anasorb CMS, then by thermal desorption and Gas Chromatography/Mass Spectrometry analysis. All sorbent tubes started off at room temperature and were stored at or below 4 C after sampling. Pumps were calibrated pre and post sampling. A sample was taken of each shop background. Personal samples were taken for the duration of the task. Area samples were taken for near tasks (i.e. near bondo). Samples were analyzed and solvent concentrations were calculated. A total of 126 samples were included in the analysis.

Objectives

This paper will characterize and assess solvent exposure collected from the SPRAY study through three specific objectives.

1) The first objective of this paper is to characterize solvent exposure on an individual basis by auto body shop tasks and sampling time.
2) The second objective is to determine if solvent concentrations fall below current regulatory standards as set by OSHA, NIOSH, and ACGIH.
3) The third objective is to determine predictive factors for solvent exposure levels, including indoor temperature, outdoor temperature, indoor relative humidity, outdoor relative humidity, booth type, ventilation (bay door and general exhaust), paint type, and specific task.

Previous papers often characterized and described solvent exposure (i.e. mean, range, sums), but there is very little literature on further statistical analysis being conducted on solvent data. This paper will not only characterize solvent exposure, but also model solvent exposure by a number of predictor variables to determine which factors effect solvent concentration the most.

Methods

Statistical Analysis

All statistical analysis was performed in SAS 9.3 (SAS Institute, Cary, NC). A log transformation was first applied on all the solvent concentrations to normalize the substantial skew in the distribution (see Appendix I).

To fulfill the first objective, the auto body shop tasks were classified into 9 task categories. This included: spray, near spray, far spray, bondo application, near bondo, background (office, shop, and all day), gun cleaning, mixing, and wiping. The natural log of each solvent was run by task in the proc means procedure to determine the solvent concentration of each solvent by task. Non-detectable samples were excluded from the analysis. Results were exponentiated.

To fulfill the second objective, the PEL and STEL were determined for each of the targeted solvents. The maximum value of each solvent concentration was determined using the proc means procedure. If a maximum value for a solvent was greater than the PEL or STEL, the number of samples that went over the regulatory standard for that solvent was noted.

To fulfill the third object, a regression model was created for each solvent using the proc glm procedure. A bivariate model was first created to determine the empirical relationship between each solvent and each predictor. Then stepwise regression (backwards elimination) was employed to determine which variables made the best model. Backward elimination begins with a full model with all the variables and the least significant variable is removed from the model one by one. The process is repeated until all the variables are significant (p value ≤ 0.05), resulting in a parsimonious regression model. In addition, two different methods were utilized to model total solvent concentration. The first method divided each solvent concentration by the relevant STEL and summed the ratios. The second method was simply a sum of each solvent concentration. The natural logs of both methods were derived to use in the model.

Non-detectable Samples

Non-detectable solvent samples were not included when characterizing solvent exposure by task. The limit of detection (LOD) is analyte and method dependent for the method the SPRAY Study employed. Typical LOD for TD tubes is 12 ng per analyte per sample for analytes like benzene, toluene, xylenes. Typical LOD for solvent desorption tubes is about 20 ug per analyte per sample. None of the samples for 2-ethoxyethanol, and 2-methoxyethanol were detectable and thus these two solvents were not included in any of the analyses.

Non-detectable solvent samples were included in the bivariate and parsimonious regression models. Solvent samples that qualified as non-detects were still quantified for solvent concentration. Each measurement was divided by 2 for use in the models (Croghan, *et.*al,2003).

Regulatory Standards

Regulatory limits were measured in mg/m3. For Benzene and Styrene, some or all regulatory standards were only presented in PPM. PPM was converted to mg/m^3 using the equation: mg/m^3= (ppm value)(molecular weight)/24.45 where 24.45 is a conversion factor that represents the volume of one mole of gas (CCOHS, 2014). The molecular weight of benzene is 78.11. The molecular weight of styrene is 104.15.

The PEL (Permissible Exposure Level) and STEL (Short Term Exposure Level) were used to establish whether solvent exposure levels fell below current permissible levels during auto body repair tasks. PEL is a time weighted average over an 8 hour period; it is set by OSHA and has regulatory power. Since all of the samples collected were of short term tasks ranging from 2-51 minutes, except for background/all day samples, the PEL was used to approximate day long time weighted exposure.

OSHA does not typically have regulatory standards for STELs. Instead, STELs were collected from ACGIH and CAL/OSHA. STEL addresses the average exposure over a 15 minute period. Since all the samples collected were for single short-term tasks, STELs were compared to single tasks. There is no published STEL for Ethyl Acetate, so the Excursion Limit (OSHA) was used as a substitution. An excursion limit means that a worker exposure level may exceed 3 times the PEL-TWA as long it is for no more than 30 minutes during the workday (Oregon OSHA, 2013).

Results

Solvent Concentrations by Task Status and Sample Time

Acetone

113 task samples were included in the acetone means procedure. There were 2 non-detectable samples in the spray tasks and 1 non-detectable sample in the bondo tasks. Gun cleaning had the highest average solvent concentration, with an average of 80.82 mg/m^3. The average acetone concentration for all tasks is 4.40 mg/m3 (Table 2).

MEK

81 task samples were included in the MEK means procedure. There were a total of 36 non-detectable samples. Mixing had the highest average solvent concentration, with an average of 3.10 mg/m3. The average MEK concentration for all tasks is 0.67 mg/m3 (Table 2).

Benzene

34 task samples were included in the benzene means procedure. There were a total of 82 non-detectable samples. Spraying had the highest average solvent concentration, with an average of 0.51 mg/m3. The average benzene concentration for all tasks is 0.07 mg/m3 (Table 2).

Ethyl Acetate

75 task samples were included in the ethyl acetate means procedure. There were a total of 40 non-detectable samples. Spraying had the highest average solvent concentration, with an average of 5.65 mg/m3. However, spraying had the highest sample with a concentration of 114.69 mg/m3. The average ethyl acetate concentration for all tasks is 1.21 mg/m3 (Table 2).

MIBK

80 task samples were included in the MIBK means procedure. There were a total of 36 non-detectable samples. Gun cleaning had the highest average solvent concentration, with an average of 6.37 mg/m3. However, spraying had the highest sample with a concentration of 76.88 mg/m3. The average MIBK concentration for all tasks is 0.80 mg/m3 (Table 2).

Toluene
114 task samples were included in the toluene means procedure. There were a total of 3 non-detectable samples. Gun cleaning had the highest average solvent concentration, with an average of 76.88 mg/m3. However, spraying had the highest sample with a concentration of 722.16 mg/m3. The average toluene concentration for all tasks is 8.18 mg/m3 (Table 2).

Butyl Acetate
98 task samples were included in the toluene means procedure. There were a total of 17 non-detectable samples. Gun cleaning had the highest average solvent concentration, with an average of 24.10 mg/m3. However, spraying had the highest sample with a concentration of 233.28 mg/m3. The average butyl acetate concentration for all tasks is 2.78 mg/m3 (Table 2).

Ethyl Benzene
79 task samples were included in the ethyl benzene means procedure. There were a total of 36 non-detectable samples. Gun cleaning had the highest average solvent concentration, with an average of 2.23 g/m3. However, spraying had the highest sample with a concentration of 24.34 mg/m3. The average butyl acetate concentration for all tasks is 0.46 mg/m3 (Table 2).

M&P Xylene
76 task samples were included in the M&P Xylene means procedure. There were a total of 39 non-detectable samples. Gun cleaning had the highest average solvent concentration, with an average of 10.51 g/m3. However, spraying had the highest sample with a concentration of 208.98 mg/m3. The average M&P Xylene concentration for all tasks is 1.35 mg/m3 (Table 2).

O Xylene
62 task samples were included in the O Xylene means procedure. There were a total of 53 non-detectable samples. Spraying had the highest average solvent concentration, with an average of 1.15 g/m3. However, bondo application had the highest sample with a concentration of 171.10 mg/m3. The average O Xylene concentration for all tasks is 0.37 mg/m3 (Table 2).

Styrene
104 task samples were included in the styrene means procedure. There were a total of 11 non-detectable samples. Bondo application had the highest average solvent concentration, with an average of 12.58 g/m3. Bondo application also had the highest sample with a concentration of 52.58 mg/m3. The average styrene concentration for all tasks is 0.45 mg/m3 (Table 2).

Sample Time
102 task samples included sampling times. The range for sampling time ranged from 2-448 minutes because of the day long and background samples. The range for sampling time for auto body shop tasks is 2-51 minutes. Spraying and gun cleaning have the lowest sample time.

<u>*Solvent Concentration and Regulatory Standards*</u>

All of the samples fell below current regulatory limits with the exception of one sample. A spraying (primer) task with duration of 5 minutes had a toluene concentration of 720.906 mg/m3, which is above the 560 mg/m3 STEL (Table 3).

Modeling of Predictor Variables

Acetone

In the bivariate analysis, general exhaust, paint type, and task were statistically significant (p> 0.001). Outdoor temperature was relatively significant (p=0.061). In the parsimonious regression model, general exhaust and task were significant predictors of acetone concentration. Both outdoor temperature (p=0.060) and bay door use (0.054) were marginally significant. The Parameter estimates show that as temperature goes up, acetone concentration goes down, but at a very minimal rate. Gun cleaning has 6.185 times the acetone concentration as the background measurements. The model had an r-square value of 0.450 (Table 4).

MEK

In the bivariate analysis, outdoor temperature, general exhaust, paint type, and task were statistically significant. In the parsimonious regression model, outdoor temperature, indoor relative humidity, outdoor relative humidity, booth type, bay door use, and task were all statistically significant predictors of MEK concentration. Paint type was marginally significant with a p value of 0.072. MEK has the greatest number significant predictor variables in the final model. With prep station as the comparison group, all other booth types had a positive correlation with acetone concentration. Gun cleaning has 4.624 times the MEK concentration as the background measurements. The model had an r-square value of 0.682 (Table 5).

Benzene

In the bivariate analysis, paint type and task were statistically significant. In the parsimonious regression model, only task was a statistically significant predictor of benzene concentration (p<0.001). The parameter estimates show that, with background as the comparison group, all tasks have a positive correlation with benzene concentration. Spraying and gun cleaning have the most significant positive association with benzene concentration. The r-square value is 0.333 (Table 6).

Ethyl Acetate

In the bivariate analysis, indoor temperature, outdoor temperature, indoor relative humidity, and task had statistically significant values. In the parsimonious regression model, outdoor temperature, indoor relative humidity, and task all had very significant p-values of <0.001. Both outdoor temperature and indoor relative humidity have a slight negative correlation with ethyl acetate concentration. Gun cleaning and mixing have the most significant positive correlation with ethyl acetate concentration. The r-square value is 0.563 (Table 7).

MIBK

In the bivariate analysis, booth type, general exhaust, paint type, and task were statistically significant. In the parsimonious regression model, outdoor temperature, booth type, general exhaust, and task were statistically significant predictors of MIBK concentration. With background as the comparison group, gun cleaning and spraying had the greatest positive correlative with MIBK concentration. With prep station as the comparison group, all the other booth types (including no booth) had a positive correlation with MIBK concentration. The model had an r-square value of 0.568 (Table 8).

Toluene
In the bivaraite analysis, booth type, general exhaust, paint type, and task were statistically significant. In the parsimonious regression model, general exhaust and task were both significant predictors of toluene concentration (p<0.001). With general exhaust on as the comparison, general exhaust off has a negative correlation with toluene concentration (toluene concentration decreases if general exhaust is off). The model had an r-square value of 0.480 (Table 9).

Butyl Acetate
In the bivariate analysis, indoor temperature, outdoor temperature, booth type, paint type, and task were statistically significant. In the parsimonious regression model, indoor temperature, paint type, and task were statistically significant. With not painting as the comparison group, painting-clear, primer, and sealer all have a negative correlation with butyl acetate concentration. With background as the comparison group, gun cleaning and spraying had the greatest positive correlation with solvent concentration. Outdoor relative humidity (p=0.058) was marginally significant. The model had an r-square value of 0.601 (Table 10).

Ethyl Benzene
In the bivariate analysis, paint type and task were statistically significant. Outdoor temperature (p=0.062) and general exhaust (0.057) were marginally significant. In the parsimonious regression model, outdoor temperature (p=0.005) and task (p<0.001) were statistically significant. With background as the comparison group, gun cleaning and spraying had the greatest positive correlation with ethyl benzene concentration. The r-square value of the model was 0.446 (Table 11).

M&P Xylene
In the bivariate analysis, outdoor temperature, general exhaust, paint type, and task were statistically significant. In the parsimonious regression model, indoor temperature and paint type were significant variables. With not painting as the comparison group, all other types of paint had a positive correlation with M&P Xylene in the parsimonious model. Single stage and sealer had the greatest parameter estimate. The r-square value of the model was 0.388 (Table 12).

O Xylene
In the bivariate analysis, outdoor temperature, indoor relative humidity, general exhaust, paint type, and task were statistically significant. In the parsimonious regression model, indoor relative humidity and task were significant variables. With background as the comparison group, gun cleaning and spraying had the greatest positive correlation with O Xylene concentration. The r-square value of the model was 0.400 (Table 13).

Styrene
In the bivariate analysis, task was statistically significant. In the parsimonious model, task was a statistically significant predictor of styrene concentration.With background as the comparison group, bondo and near bondo had the most significant positive correlation with styrene concentration. The model had an r-square value of 0.538 (Table 14).

Total Solvent (Solvent Concentration/STEL)

In the bivariate analysis, general exhaust, paint type, and task were statistically significant. In the parsimonious model, outdoor temperature, general exhaust, and task were significant predictors of total solvent concentration. With general exhaust on as the comparison group (parameter estimate=0), general exhaust off has a negative correlation with total solvent concentration. With background as the comparison group, gun cleaning and bondo had the greatest positive correlation with solvent concentration. The model had an r-square value of 0.665 (Table 15).

Total Solvent (Sum of Solvent Concentrations)

In the bivariate analysis, general exhaust, paint type, and task were statistically significant. In the parsimonious model, outdoor temperature, general exhaust, and task were significant predictors of total solvent concentration. With general exhaust on as the comparison group (parameter estimate=0), general exhaust off has a negative correlation with total solvent concentration. With background as the comparison group, gun cleaning and mixing had the greatest positive correlation with solvent concentration. The model had an r-square value of 0.662 (Table 16).

Discussion

There is a very limited number of solvent exposure assessment studies published as of the last 30 years. The health effects of solvents are well understood, so much of the recent literature surrounding solvent exposure deal with estimated chronic exposure in correlation with a health effect that has a long latency period, such as leukemia, brain damage, and hearing impairment. Auto body shops face unique problems when it comes to chemical exposure due to the small size of most shops, gaps in worker training and regulatory compliance, and adherence to personal protective use (Enander, 1998).

Regulatory Standards

Recent exposure assessments like this one have found that most, if not all, solvent concentrations fall below worker exposure limits. However, the 1984 Jayjock paper found that STELs are often greatly exceeded. Jayjock's paper is one of the many studies performed in the 1970's and 1980's on workplace solvent exposure when there was substantial interest in occupational solvent exposure. Since those studies, measures ranging from policies to paints have been changed or implemented to control exposure. Although these changes have lowered solvent exposure, it does not mean that solvent exposure is a non-issue in the 21st century. Chronic solvent exposure over the course of several decades, although under regulatory limits, may still cause eventual health effects.

Furthermore, it is important to remember that regulatory standards do not always equate to "safe" levels of exposure. There is often a gap between what science considers "safe" and the definition of "safe" that makes it into public policy. Even the Assistant Secretary of Labor for OSHA stated that the "health and safety community recognizes that the PELs are badly out of date and efforts should be made to update these values which are now over 40 years old" (Corbin, 2012).

Mergler et al., 1987 and *Winder et al.,1992* both indicated high concentrations of toluene in their studies and toluene was the one sample that went over the STEL in this study. This indicates that further research should focus on toluene and ways to lower toluene levels in occupational exposure. The OSHA PEL (TWA) for toluene is 200 ppm (750 mg/m^3), which dates back to 1946 when the primary concern was to prevent central nervous system depression (Corbin, 2012). However, in 2007, ACGIH updated their threshold limit value (TWA) for toluene at 20 ppm (75 mg/m^3) when it was discovered that toluene can cause female reproductive system damage and pregnancy loss (OSHA Toluene, 2014).

Models

This study found that, except for M&P Xylene, task was a significant predictor variable for all solvents and total solvent concentrations. The tasks that produced the highest levels of solvent concentrations are: gun cleaning, spraying, and mixing. Previous studies often focused on task type when assessing solvent exposure and this model confirmed that it is a valuable variable to include. Temperature and/or relative humidity was included in 10 of the 13 parsimonious models, although the parameter estimates were incredibly small.

Booth type was only included in 2 of the 13 parsimonious models. Semi-downdraft had the lowest correlation with solvent concentration, which was unexpected. Downdraft booths are typically the most effective against airborne exposures because the design has air entering through the ceiling and getting immediately sucked out through the floor (Goyer, 1995). The ventilation parameters with the greatest effect on booth performance are air velocity, flow direction, and flow homogeneity, so it is possible that the semi-downdraft booths in question had more favorable air velocity and flow (Goyer, 1995).

Bay door (open or closed) was only included in one of the parsimonious models. This may be due to the fact that general exhaust (on and off) was a better indicator of ventilation, so bay door use was insignificant in comparison and thus dropped in the regression model. The results for general exhaust off having a negative correlation with solvent concentration may seem flawed, but it is important to interpret the results in the context of an auto body shop. It is possible that workers only turned the exhaust on for large tasks with extremely high exposure levels and left it off for small tasks. Paint type was included in 3 (MEK, butyl acetate, and m&p xylene) of the 13 parsimonious models. Single stage paint had the greatest positive correlation with solvent concentration.

The two methods of modeling total solvent concentration yielded extremely similar results. The same variables (outside temperature, general exhaust, and task) ended up in the parsimonious model. Both models also yielded high r-square values (0.665, 0.662). The r-square values for the 13 models ranged from 0.333-0.682, indicating that the data fits well onto the regression line.

Limitations

A limitation of this study is the small numbers of samples in each category after the samples were divided into different categories (i.e. task type). The study had 126 samples overall. However, once the samples were categorized, many groups had less than 10 samples.

Conclusion

In conclusion, most solvent concentrations in the SPRAY study fall well below regulatory standards. However, this is not necessarily an indicator of safety. Task is the best predictor variable for solvent concentrations; task was included in 12 of the 13 parsimonious models (not included in the model for m&p xylene). Gun cleaning, spraying, and mixing had the highest level of solvent exposure. Finally, summation of the solvents is just as good of an estimation of total solvent concentration in comparison to dividing each solvent by the STEL. The two parsimonious model for total solvent concentration included the same 3 variables (outdoor temperature, general exhaust, and task) and had near identical r-square values (solvent concentration/STELs= 0.665, sum of concentrations=0.662). Future studies should explore the health effects of chronic exposure to permissible levels of solvents.

Table 1: Health effects of auto body shop solvents measured in the SPRAY Study

Solvent	Health Effect
Acetone	Slight eye, nose, and respiratory irritation
MEK	Eyes, nose, and throat irritation
Benzene	Leukemia, CNS excitation leading to CNS depression, loss of consciousness, respiratory paralysis, death, nonmalignant blood disorders, eye, nose, and respiratory irritation
Ethyl Acetate	Mild narcosis (high concentrations), mild eye, nose, and upper respiratory irritation
MIBK	Dizziness, headache, weakness, narcosis, coma
Toluene	CNS depression, irritation of eyes, mucous membranes, and upper respiratory tract
Butyl Acetate	Narcosis, eye and mucous membrane irritation
Ethyl Benzene	Eye, skin, and throat irritation
Xylene	Liver enlargement, narcosis, mild anemia, eye, nose, and throat irritation
Styrene	CNS depression, irritation of lungs, eye, nose, and skin irritation
2-ethoxyethanol	Mild eye, nose, throat, skin irritation, blood disturbances, suspect reproductive hazard
2-methoxyethanol	Mild eyes, nose, throat, skin irritation, blood disorders, CNS effects, suspect reproductive hazard

Source: OSHA- Chemical Sampling Information

Table 2: Average and Range of Solvent Concentrations (mg/m^3) and Sample Time by Auto body Shop Tasks

	Acetone		MEK		Benzene		EA		MIBK		Toluene	
Task	# of samples (ND)*	GM (Range)**	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)
Spray	50 (2)	8.35 0.71-213.20	33 (19)	1.88 0.13-70.26	8 (44)	0.51 0.11-2.08	31 (20)	3.83 0.27-114.69	38 (14)	3.46 0.20-76.88	49 (3)	16.48 0.99-722.16
Near Spray	9 (0)	2.37 0.02-62.32	6 (3)	0.86 0.14-2.64	1 (7)	0.02	3 (5)	0.79 0.30-1.59	4 (4)	0.75 0.18-2.42	9 (0)	6.84 0.52-484.08
Far Spray	1 (0)	0.25	1 (0)	0.02	0 (1)	-	1 (0)	0.05	1 (0)	0.01	1 (0)	1.13
Bondo App	12 (1)	1.96 0.15-19.34	5 (8)	0.45 0.11-4.91	3 (10)	0.04 0.01-0.55	7 (6)	0.13 0.01-8.69	4 (9)	0.16 0.12-0.71	13 (0)	6.70 0.65-79.22
Near Bondo	6 (0)	0.86 0.22-3.07	3 (3)	0.39 0.10-1.39	3 (3)	0.14 0.02-0.39	3 (3)	1.30 0.22-8.27	3 (3)	0.30 0.01-1.98	6 (0)	6.77 2.54-11.61
Background	23 (0)	0.84 0.05-9.80	23 (1)	0.07 0.01-5.83	16 (8)	0.02 0.00-0.14	20 (4)	0.11 0.02-3.02	20 (4)	0.08 0.01-0.42	24 (0)	0.92 0.12-6.12
Gun Cleaning	3 (0)	80.82 22.47-488.94	3 (0)	1.62 0.92-2.70	0 (3)	-	3 (0)	3.79 1.47-8.69	3 (0)	6.37 1.34-46.63	3 (0)	76.88 30.64-125.49
Mixing	8 (0)	10.61 1.44-66.17	7 (1)	3.10 0.70-70.97	2 (6)	0.04 0.03-0.05	6 (2)	5.65 1.13-40.95	6 (2)	1.09 0.08-4.11	8 (0)	24.34 6.19-90.22
Wiping	1 (0)	8.35	0 (1)	-	1 (0)	1.20	1 (0)	0.04	1 (0)	1.50	1 (0)	97.73
Total	113 (3)	4.40 0.02-927.27	81 (36)	0.67 0.01-70.97	34 (82)	0.07 0-3.13	75 (40)	1.21 0.02-114.69	80 (36)	0.80 0.01-76.88	114 (3)	8.18 0.12-722.16

	BA		EB		MP Xylene		O Xylene		Styrene		Sample Time	
Task	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	GM (Range)	# of samples (ND)	Mean (Range)
Spray	45 (6)	10.30 0.44-233.28	34 (17)	1.39 0.14-24.34	33 (18)	1.10 0.03-208.98	27 (24)	1.15 0.07-15.52	51	0.13 0.02-10.10	44	8.52 2-26
Near Spray	6 (2)	2.00 0.26-15.21	4 (4)	0.81 0.44-2.49	5 (3)	0.99 0.26-8.78	3 (5)	0.35 0.11-1.54	8	0.06 0.01-0.81	9	19.67 10-44
Far Spray	1	0.08	1	0.02	1	0.01	0 (1)	-	0	-	1	237
Bondo App	7 (6)	0.69 0.26-1.83	5 (8)	0.11 0.04-0.33	5 (8)	0.34 0.11-0.82	5 (8)	0.28 0.04-171.10	13	12.58 1.81-52.58	12	23.08 10-51
Near Bondo	5 (1)	0.69 0.25-1.83	4 (2)	0.19 0.06-0.77	3 (3)	0.67 0.22-2.47	3 (3)	0.16 0.07-0.49	6	1.02 0.28-4.11	4	26.50 10-42
Background	23 (1)	0.23 0.01-5.77	20 (4)	0.06 0.01-0.45	19 (5)	0.17 0.01-1.29	17 (7)	0.05 0.00-0.52	21 (3)	0.05 0.00-1.45	21	367.43 142-448
Gun Cleaning	3	24.10 3.43-104.82	3	2.23 0.37-10.40	2 (1)	10.51 6.12-18.21	1 (2)	3.50	0 (3)	-	3	5.33 2-9
Mixing	8	3.68 0.70-18.77	7 (1)	0.46 0.06-4.02	7 (1)	1.48 0.21-15.21	5 (3)	0.23 0.03-2.75	3 (5)	0.37 0.11-3.83	7	17.29 5-45
Wiping	0 (1)	0.04	1	1.56	1	2.44	1	0.55	1	0.39	1	6
Total	98 (17)	2.78 0.01-233.28	79 (36)	0.46 0.01-24.34	76 (39)	1.35 0.01-305.59	62 (53)	0.37 0-171.1	104 (11)	0.45 0-52.58	102	78.98 2-448

*ND= Non-detectable samples (not included in solvent mean and range)
**GM= Geometric Mean, Range= minimum-maximum
Note: Total values may not add to 126 due to missing variables

Table 3: Permissible Exposure Limits (PEL) and Short Term Exposure Limits (STEL) for Solvent Concentrations

Solvent	Permissible Exposure Limit (PEL) as a TWA	# of samples above limit/total samples	Short term exposure limit (STEL)	# of samples above limit/total samples
Acetone	2,400 mg/m3[1]	0/116	1780 mg/m3[2,3]	0/116
MEK	590 mg/m3[1]	0/117	885 mg/m3[2,3]	0/117
Benzene*	3.2 mg/m3[1]	0/116	15.97 mg/m3[1,3] 8 mg/m3[2]	0/116
Ethyl Acetate	1,400 mg/m3[1]	0/115	4,200 mg/m	0/116
MIBK	410 mg/m3[1]	0/116	307 mg/m3[2,3]	0/116
Toluene	750 mg/m3[1]	0/117	560 mg/m3[3]	1/117
Butyl Acetate	710 mg/m3[1]	0/115	950 mg/m3[2,3]	0/115
Ethyl Benzene	435 mg/m3[1]	0/115	545 mg/m3[3]	0/116
M and P Xylene	435 mg/m3[1]	0/115	651 mg/m3[2,3]	0/115
O Xylene	435 mg/m3[1]	0/115	651 mg/m3[2,3]	0/115
Styrene	425 mg/m3[1] *	0/115	170.39 mg/m3[2] 425 mg/m3[3]	0/115

1) OHSA PELs, 2) ACGHI STELs TLV, 3) CAL/OSHA STELs PEL
Source: OSHA- Chemical Sampling Information

Table 4: Bivariate Analysis and Parsimonious Regression Model for explaining Acetone Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.450)
Indoor temp.	-0.018	0.439		
Outdoor temp.	-0.023	0.061	-0.020	0.060*
Indoor relative humidity	-0.011	0.425		
Outdoor relative humidity	-0.007	0.567		
Booth Type	Crossdraft: 0.679 Downdraft: 0.381 Non-booth: -0.119 Semidowndraft: 1.556 Prep: 0.000	0.597		
Baydoor	Closed: 0.342 Open: 0.000	0.443	Closed: 0.934 Open: 0.000	0.054*
General Exhaust	Off: -2.221 On: 0.000	<0.001	Off: -1.843 On: 0.000	0.008
Paint Type	Base: 1.057 Clear: 2.167 Primer: 0.942 Sealer: 2.257 Single Stage: 2.554 Not paint: 0.000	<0.001		
Task	Bondo: 0.481 Gun Cleaning: 4.570 Mixing: 2.538 Near Bondo: 0.030 Near Spray: 1.043 Spray: 2.205 Background: 0.000	<0.001	Bondo: 0.794 Gun Cleaning: 6.185 Mixing: 2.079 Near Bondo: -0.055 Near Spray: 1.929 Spray: 1.734 Background: 0.000	<0.001

Table 5: Bivariate Analysis and Parsimonious Regression Model for explaining MEK Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.682)
Indoor temp.	-0.047	0.084		-
Outdoor temp.	-0.049	<0.001	-0.065	<0.001
Indoor relative humidity	-0.019	0.255	0.063	0.002
Outdoor relative humidity	-0.020	0.198	-0.067	<0.001
Booth Type	Crossdraft: 1.911 Downdraft: -0.017 Non-booth: -0.320 Semidowndraft: 0.550 Prep: 0.000	0.448	Crossdraft: 3.860 Downdraft: 4.981 Non-booth: 5.628 Semidowndraft: 1.228 Prep: 0.000	0.005
Baydoor	Closed: 0.670 Open: 0.000	0.208	Closed: 1.445 Open: 0.000	0.018
General Exhaust	Off: -2.263 On: 0.000	0.004		-
Paint Type	Base: 1.759 Clear: 2.485 Primer: 2.028 Sealer: 2.763 Single Stage: 2.364 Not paint: 0.000	<0.001	Base: 0.604 Clear: 2.240 Primer: 2.262 Sealer: 2.905 Single Stage: 1.311 Not paint: 0.000	0.072*
Task	Bondo: 0.067 Gun Cleaning: 3.396 Mixing: 3.491 Near Bondo: 0.190 Near Spray: 1.398 Spray: 2.426 Background: 0.000	<0.001	Bondo: 0.661 Gun Cleaning: 4.624 Mixing: 1.917 Near Bondo: 1.094 Near Spray: 2.931 Spray: 1.479 Background: 0.000	0.036

Table 6: Bivariate Analysis and Parsimonious Regression Model for explaining Benzene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.333)
Indoor temp.	0.021	0.289		-
Outdoor temp.	-0.002	0.839		-
Indoor relative humidity	-0.003	0.786		-
Outdoor relative humidity	0.003	0.768		-
Booth Type	Crossdraft: 0.215 Downdraft: 0.923 Non-booth: -0.015 Semidowndraft: 0.457 Prep: 0.000	0.325		-
Baydoor	Closed: -0.369 Open: 0.000	0.365		-
General Exhaust	Off: -1.068 On: 0.000	0.074		-
Paint Type	Base: 1.056 Clear: 1.349 Primer: 1.098 Sealer: 1.442 Single Stage: 0.478 Not paint: 0.000	0.016		-
Task	Bondo: 1.248 Gun Cleaning: 2.319 Mixing: 1.742 Near Bondo: 1.844 Near Spray: 1.125 Spray: 2.555 Background: 0.000	<0.001	Bondo: 1.248 Gun Cleaning: 2.319 Mixing: 1.742 Near Bondo: 1.844 Near Spray: 1.125 Spray: 2.555 Background: 0.000	<.0.001

Table 7: Bivariate Analysis and Parsimonious Regression Model for explaining Ethyl Acetate Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Bivariate Analysis Parameter Estimates	Parsimonious Model P-value (R-square= 0.563)
Indoor temp.	-0.083	0.006		-
Outdoor temp.	-0.073	<0.001	-0.054	<0.001
Indoor relative humidity	-0.052	<0.006	-0.041	<0.001
Outdoor relative humidity	-0.010	0.572		-
Booth Type	Crossdraft: 0.654 Downdraft: -1.457 Non-booth: -1.267 Semidowndraft: 0.001 Prep: 0.000	0.526		-
Baydoor	Closed: 0.969 Open: 0.000	0.102		-
General Exhaust	Off: 0.152 On: 0.000	0.863		-
Paint Type	Base: 0.813 Clear: 1.374 Primer: 1.220 Sealer: 1.135 Single Stage: 1.871 Not paint: 0.000	0.229		-
Task	Bondo: 1.036 Gun Cleaning: 4.379 Mixing: 3.492 Near Bondo: 1.359 Near Spray: 0.475 Spray: 2.792 Background: 0.000	<0.001	Bondo: 1.078 Gun Cleaning: 6.832 Mixing: 4.280 Near Bondo: 0.376 Near Spray: 1.144 Spray: 2.849 Background: 0.000	<.0.001

Table 8: Bivariate Analysis and Parsimonious Regression Model for explaining MIBK Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.568)
Indoor temp.	-0.029	0.314		-
Outdoor temp.	-0.025	0.105	-0.038	0.003
Indoor relative humidity	-0.019	0.281		-
Outdoor relative humidity	-0.004	0.826		-
Booth Type	Crossdraft: 3.592 Downdraft: 3.173 Non-booth: 0.692 Semidowndraft: 0.970 Prep: 0.000	<0.001	Crossdraft: 4.624 Downdraft: 4.594 Non-booth: 3.047 Semidowndraft: 1.206 Prep:0.000	0.036
Baydoor	Closed: 0.442 Open: 0.000	0.452		-
General Exhaust	Off: -1.889 On: 0.000	0.028	Off: -2.778 On: 0.000	0.002
Paint Type	Base: 2.320 Clear: 3.433 Primer: 1.200 Sealer: 4.177 Single Stage: 2.004 Not paint: 0.000	<0.001		-
Task	Bondo: -0.078 Gun Cleaning: 5.168 Mixing: 2.552 Near Bondo: 0.522 Near Spray: 1.128 Spray: 3.548 Background: 0.000	<0.001	Bondo: -0.124 Gun Cleaning: 3.830 Mixing: 2.202 Near Bondo: 0.383 Near Spray: 1.631 Spray: 2.636 Background: 0.000	<0.001

Table 9: Bivariate Analysis and Parsimonious Regression Model for explaining Toluene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.480)
Indoor temp.	0.012	0.314		-
Outdoor temp.	-0.013	0.105		-
Indoor relative humidity	-0.017	0.281		-
Outdoor relative humidity	-0.010	0.826		-
Booth Type	Crossdraft: 2.229 Downdraft: 1.135 Non-booth: 0.988 Semidowndraft: 0.442 Prep: 0.000	<0.001		-
Baydoor	Closed: -0.157 Open: 0.000	0.452		-
General Exhaust	Off: -1.921 On: 0.000	0.028	Off: -2.357 On: 0.000	<0.001
Paint Type	Base: 0.953 Clear: 1.246 Primer: 1.605 Sealer: 1.587 Single Stage: 0.822 Not paint: 0.000	<0.001		-
Task	Bondo: 1.989 Gun Cleaning: 4.432 Mixing: 3.282 Near Bondo: 2.002 Near Spray: 2.014 Spray: 2.685 Background: 0.000	<0.001	Bondo: 2.087 Gun Cleaning: 4.530 Mixing: 3.380 Near Bondo: 2.100 Near Spray: 2.112 Spray: 2.557 Background: 0.000	<0.001

Table 10: Bivariate Analysis and Parsimonious Regression Model for explaining Butyl Acetate Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.601)
Indoor temp.	-0.071	0.013	-0.078	<0.001
Outdoor temp.	-0.039	0.011		-
Indoor relative humidity	-0.005	0.799		-
Outdoor relative humidity	0.014	0.402	0.027	0.058*
Booth Type	Crossdraft: -1.041 Downdraft: 0.143 Non-booth: -2.196 Semidowndraft: -2.676 Prep: 0.000	0.003		-
Baydoor	Closed: 0.377 Open: 0.000	0.522		-
General Exhaust	Off: -1.234 On: 0.000	0.153		-
Paint Type	Base: 2.887 Clear: 2.336 Primer: 1.872 Sealer: 2.401 Single Stage: 3.928 Not paint: 0.000	<0.001	Base: 1.053 Clear: -0.516 Primer: -0.808 Sealer: -1.078 Single Stage: 3.661 Not paint: 0.000	<0.001
Task	Bondo: -0.543 Gun Cleaning: 4.887 Mixing: 3.011 Near Bondo: 0.830 Near Spray: 1.348 Spray: 3.518 Background: 0.000	<0.001	Bondo: 0.037 Gun Cleaning: 3.455 Mixing: 2.419 Near Bondo: 0.722 Near Spray: 0.626 Spray: 3.514 Background: 0.000	0.006

Table 11: Bivariate Analysis and Parsimonious Regression Model for explaining Ethyl Benzene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.446)
Indoor temp.	-0.036	0.151		-
Outdoor temp.	-0.025	0.062	-0.032	0.005
Indoor relative humidity	-0.019	0.223		-
Outdoor relative humidity	-0.003	0.806		-
Booth Type	Crossdraft: -0.177 Downdraft: -0.086 Non-booth: -1.230 Semidowndraft: -2.512 Prep: 0.000	0.171		-
Baydoor	Closed: -0.376 Open: 0.000	0.456		-
General Exhaust	Off: -1.402 On: 0.000	0.057		-
Paint Type	Base: 1.723 Clear: 2.267 Primer: 1.282 Sealer: 3.033 Single Stage: 1.853 Not paint: 0.000	<0.001		-
Task	Bondo: 0.321 Gun Cleaning: 4.372 Mixing: 2.466 Near Bondo: 1.098 Near Spray: 1.496 Spray: 2.976 Background: 0.000	<0.001	Bondo: 0.035 Gun Cleaning: 4.662 Mixing: 2.169 Near Bondo: 0.087 Near Spray: 1.541 Spray: 2.738 Background: 0.000	<0.001

Table 12: Bivariate Analysis and Parsimonious Regression Model for explaining M&P Xylene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.388)
Indoor temp.	-0.055	0.084	-0.080	0.004
Outdoor temp.	-0.035	0.040		-
Indoor relative humidity	-0.033	0.089		-
Outdoor relative humidity	-0.016	0.379		-
Booth Type	Crossdraft: -0.922 Downdraft: 0.164 Non-booth: -1.529 Semidowndraft: -3.369 Prep: 0.000	0.084		-
Baydoor	Closed: -0.302 Open: 0.000	0.626		-
General Exhaust	Off: -1.854 On: 0.000	0.040		-
Paint Type	Base: 2.473 Clear: 2.730 Primer: 1.507 Sealer: 3.887 Single Stage: 2.247 Not paint: 0.000	<0.001	Base: 3.127 Clear: 3.386 Primer: 1.604 Sealer: 3.553 Single Stage: 4.959 Not paint: 0.000	<0.001
Task	Bondo: 0.066 Gun Cleaning: 3.567 Mixing: 2.834 Near Bondo: 0.531 Near Spray: 1.408 Spray: 3.020 Background: 0.000	<0.001		-

Table 13: Bivariate Analysis and Parsimonious Regression Model for explaining O Xylene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.400)
Indoor temp.	-0.035	0.201		-
Outdoor temp.	-0.032	0.031		-
Indoor relative humidity	-0.044	0.009	-0.055	<0.001
Outdoor relative humidity	-0.015	0.324		-
Booth Type	Crossdraft: -0.682 Downdraft: -0.696 Non-booth: -1.665 Semidowndraft: -2.318 Prep: 0.000	0.329		-
Baydoor	Closed: -0.329 Open: 0.000	0.537		-
General Exhaust	Off: -1.816 On: 0.000	0.019		-
Paint Type	Base: 1.499 Clear: 1.812 Primer: 1.097 Sealer: 3.489 Single Stage: 2.068 Not paint: 0.000	<0.001		-
Task	Bondo: 1.260 Gun Cleaning: 3.003 Mixing: 1.925 Near Bondo: 1.104 Near Spray: 1.423 Spray: 2.909 Background: 0.000	<0.001	Bondo: 1.430 Gun Cleaning: 5.442 Mixing: 1.942 Near Bondo: 0.806 Near Spray: 0.446 Spray: 2.952 Background: 0.000	<0.001

Table 14: Bivariate Analysis and Parsimonious Regression Model for explaining Styrene Concentration

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.538)
Indoor temp.	-0.012	0.700		-
Outdoor temp.	-0.026	0.101		-
Indoor relative humidity	-0.013	0.484		-
Outdoor relative humidity	0.012	0.485		-
Booth Type	Crossdraft: 0.438 Downdraft: 0.314 Non-booth: 0.836 Semidowndraft: -0.492 Prep: 0.000	0.813		-
Baydoor	Closed: -0.640 Open: 0.000	0.237		-
General Exhaust	Off: 0.487 On: 0.000	0.543		-
Paint Type	Base: -0.517 Clear: -0.746 Primer: -0.156 Sealer: -0.873 Single Stage: -1.198 Not paint: 0.000	0.765		-
Task	Bondo: 6.010 Gun Cleaning: 0.659 Mixing: 0.496 Near Bondo: 3.504 Near Spray: 0.668 Spray: 1.404 Background: 0.000	<0.001	Bondo: 6.010 Gun Cleaning: 0.659 Mixing: 0.496 Near Bondo: 3.504 Near Spray: 0.668 Spray: 1.404 Background: 0.000	<0.001

Table 15: Bivariate Analysis and Parsimonious Regression Model for explaining Total Solvent Concentration by dividing solvent concentrations by STELs

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.665)
Indoor temp.	0.007	0.707		-
Outdoor temp.	-0.016	0.128	-0.016	0.017
Indoor relative humidity	-0.012	0.298		-
Outdoor relative humidity	-0.003	0.773		-
Booth Type	Crossdraft: 1.049 Downdraft: 1.033 Non-booth: 0.357 Semidowndraft: 0.271 Prep: 0.000	0.490		-
Baydoor	Closed: -0.355 Open: 0.000	0.344		-
General Exhaust	Off: -1.680 On: 0.000	0.002	Off: -1.989 On: 0.000	<0.001
Paint Type	Base: 0.939 Clear: 1.336 Primer: 1.026 Sealer: 1.766 Single Stage: 1.384 Not paint: 0.000	0.003		-
Task	Bondo: 3.142 Gun Cleaning: 4.023 Mixing: 2.759 Near Bondo: 1.755 Near Spray: 1.781 Spray: 2.983 Background: 0.000	<0.001	Bondo: 3.159 Gun Cleaning: 4.075 Mixing: 2.815 Near Bondo: 1.833 Near Spray: 2.392 Spray: 2.768 Background: 0.000	<0.001

Table 16: Bivariate Analysis and Parsimonious Regression Model for explaining Total Solvent Concentration by Adding Solvent Concentrations

Variables	Bivariate Analysis Parameter Estimates	Bivariate Analysis P-value	Parsimonious Model Parameter Estimates	Parsimonious Model P-value (R-square= 0.662)
Indoor temp.	-0.002	0.939		-
Outdoor temp.	-0.021	0.056	-0.022	0.003
Indoor relative humidity	-0.013	0.286		-
Outdoor relative humidity	-0.003	0.784		-
Booth Type	Crossdraft: 0.876 Downdraft: 0.728 Non-booth: -0.034 Semidowndraft: 0.163 Prep: 0.000	0.409		-
Baydoor	Closed: -0.215 Open: 0.000	0.580		-
General Exhaust	Off: -1.883 On: 0.000	<0.001	Off: -2.000 On: 0.000	<0.001
Paint Type	Base: 1.193 Clear: 1.635 Primer: 1.371 Sealer: 2.047 Single Stage: 2.135 Not paint: 0.000	<0.001		-
Task	Bondo: 2.458 Gun Cleaning: 4.447 Mixing: 3.133 Near Bondo: 1.386 Near Spray: 1.868 Spray: 3.122 Background: 0.000	<0.001	Bondo: 2.462 Gun Cleaning: 4.822 Mixing: 3.156 Near Bondo: 1.519 Near Spray: 2.535 Spray: 2.886 Background: 0.000	<0.001

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Appendix I

Proc Univariate Procedure showing Total Solvent Concentration Before and After Log Transformation

Before Log Transformation

```
                  Histogram                           #              Boxplot
  1550+*                                              1                 *
      .*                                              1                 *
      .
  1250+
      .
      .
   950+*                                              1                 *
      .*                                              2                 *
      .
   650+*                                              1                 *
      .*                                              2                 0
      .****                                           7                 0
   350+**                                             3                 |
      .****                                           7                 |
      .************                                  23              +--+--+
    50+*************************************         75              *-----*
       ----+----+----+----+----+----+----+---
       * may represent up to 2 counts


                          Normal Probability Plot
         1550+                                                          *
             |                                                       *
             |
         1250+
             |
             |
          950+                                                     *
             |                                                   **
             |                                                       ++++
          650+                                                 *++++
             |                                              +**+
             |                                          ++****
          350+                                      ++++ *
             |                                  ++++   ***
             |                              ++++ ******
           50+*  * ************************
              +----+----+----+----+----+----+----+----+----+----+----+
                   -2        -1         0        +1        +2
```

After Log Transformation

```
   Stem Leaf                     #             Boxplot
      7 33                       2                 |
      6 5889                     4                 |
      6 011122233                9                 |
      5 555777788                9                 |
      5 0000012222233334        16             +-----+
      4 55566667788899          14             |     |
      4 1122233334444           13             *--+--*
      3 5555556667778888999     19             |     |
      3 01112222234             11             +-----+
      2 56666679                 8                 |
      2 14                       2                 |
      1 7889                     4                 |
      1 0012333                  7                 |
      0 9                        1                 |
      0 4                        1                 |
     -0 2                        1                 0
     -0 95                       2                 0
        ----+----+----+----+
```

```
                    Normal Probability Plot
 7.25+                                           +++ *  *
     |                                        ++*****
     |                                     *****
     |                                  ***
     |                              *****
     |                           ****
     |                        ***+
     |                     ****
 3.25+                 *****
     |               ***+
     |             +**
     |          ++***
     |       +++***
     |    +++***
     | +++  *
     |+  * *
-0.75+*
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```