

# **Risk Trade-off Assessment Document**

## **-Solvent-**

### Summary

Development of Methodologies for Risk Trade-off Analysis toward Optimum Chemical Substance Management,

Funding provided by New Energy and Industrial Technology Development Organization (NEDO) and Ministry of Economy, Trade and Industry (METI)

May 26, 2014

National Institute of Advanced Industrial Science and Technology (AIST)  
Research Institute of Science for Safety and Sustainability (RISS)

This risk tradeoff assessment report was prepared by the Research Institute of Science for Safety and Sustainability (RISS) at the National Institute of Advanced Industrial Science and Technology (AIST). The funding of this research project, "Methodologies for Risk Trade-off Analysis toward Optimum Chemical Substance Management", was provided by the New Energy and Industrial Technology Development Organization (NEDO) and Ministry of Economy, Trade and Industry (METI) in Japan.

Authors

Hideo Kajihara	AIST
Kazuya Inoue	AIST
Hiroya Shinozaki	AIST
Masashi Gamo	AIST
Jun-ichi Takeshita	AIST
Atsushi Takai	AIST

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## **1 . Introduction**

Solvents are liquid substances used to dissolve materials. Industrial solvents are almost always “organic solvents” and consist of volatile organic compounds (VOCs) such as toluene, xylene, acetone, and alcohol. The emission mitigation and substitution for VOCs is being promoted through a PRTR system, the control and voluntary management of hazardous air pollutants, and VOC regulations. However, VOC regulations are based on the risks from secondary products (such as ozone), rather than from the impact of VOC emissions

Particularly in recent years, VOC regulations (to mitigate total VOCs by 30% between 2000~2010) have been a motivation for the mitigation and substitution of solvents. With regard to the transition in change of VOC emission by use in recent years, it is clear that paint, printing ink, and adhesives occupy a large proportion of the amount of emissions.

In this regard, the basic objective of a solvent risk trade-off assessment was set as follows. For an assessment of risk in an outdoor, atmospheric environment, the risks from secondary VOC products such as ozone, (impact on human health and rice yield), was assessed using a basic unit of risk mitigation calculated by ADMER-PRO. In a case analysis, a change in risk across Japan is assessed by focusing on the process of industrial automobile painting. Following this analysis, a developed indoor exposure assessment model (iAIR) is used to estimate the indoor environmental risk assessment and any changes to the risk to human health (across Japan) by substituting VOCs in paint, printing ink, and adhesives.

## **2. Risk Assessment for General Atmospheric Environment**

### **2.1 Basic Unit of Atmospheric Environmental Risk Mitigation by VOC Mitigation**

#### **2.1.1 Point of View for Basic Unit of Risk Mitigation**

The process of estimating the chemical risk mitigation effect expected by mitigating VOCs, uses a calculation for the changes in the concentration distribution of each substance. Although the use of this process has become simpler with the use of the ADMER-PRO developed in this project, its application is still expected to be a heavy burden for some businesses.

A Basic Unit of Risk Mitigation (BURM) is an index that shows the mitigation effect of chemical risk per unit quantity of VOC mitigated. Once this index is estimated and the value is presented, businesses should be able to estimate the risk mitigation effect from mitigating VOC emissions without undertaking the troublesome calculation of concentration distribution; which would make the process very convenient. Thus, as a method for businesses to estimate the risk mitigation effect, in addition to a direct use of the atmospheric model ADMER-PRO, this project estimates and presents the basic unit of risk mitigation using the atmospheric model, which can then be used as an index in the estimation.

### **2.1.2 Substances Considered for Basic Unit of Risk Mitigation and Hazardous Impact**

Nine substances were targeted in total: ozone, chloroethylene, dichloromethane, trichloroethylene, benzene, 1,2-dichloroethane, acrylonitrile, toluene, and xylene.

Hazardous impacts to human health were selected for each substance, as follows: “early death” was selected as a target for ozone, as it is considered the most serious impact by a substance. “Cancer” was selected for chloroethylene, dichloromethane, trichloroethylene, benzene, 1,2-dichloroethane, and acrylonitrile. “Subjective symptoms” was selected for toluene and xylene. In addition, a reduction in rice yield was also considered for ozone, as a hazardous impact to plants.

### **2.1.3 Types of Basic Unit of Risk Mitigation and Calculation Method**

As shown in “2.1.1 Point of View for Basic Unit of Risk Mitigation,” the risks from various substances with different hazardous impacts need to be considered in order to estimate the BURM of VOCs. It is useful to use an index in relation to quantifying risks in the number of cases (or the probability of occurrence) which have occurred due to hazardous impacts presented by the substances. However, these impacts have varying degree of severity and seriousness, and it would be meaningless to attempt to calculate these in a standard index. This project therefore calculates a unified risk index as a quantifiable index, in addition to calculating the number of cases related to each hazardous impact. Specifically, the following 6 risk indexes were used to calculate BURM (targeted chemical substances are noted inside parentheses): 1) to 4) are the number of cases of individual hazardous human impacts and decreases in crop yield (rice); 5) is the unified index of hazardous impacts to humans; and 6) is the unified risk index for all impacts, including an impact to crops.

- 1) Annual number of cases of early deaths (ozone).
- 2) Annual cases of carcinogenesis (6 hazardous atmospheric substances (chloroethylene, dichloromethane, trichloroethylene, benzene, 1,2-dichloroethane, acrylonitrile)).
- 3) Annual cases of subjective symptoms (health condition level C<sup>1</sup>) (toluene, xylene).
- 4) Annual decrease in rice yield (ozone).
- 5) Annual QALY (Quality Adjusted Life Year) loss (all 9 substances).
- 6) Monetary Conversion of impacts to human health (QALY) and rice yield (all 9 substances)

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<sup>1</sup> In the Risk Assessment Document Series, “Xylene” (Nakanishi & Makino 2009), a quantitative risk assessment is being conducted by dividing up health conditions into the following 3 categories: Health condition A (Muscular strength of arms and legs have become weak + difficulty hearing + cannot focus on a task), health condition B (Having difficulty with sense of smell + throat feels strange) and health condition C (health condition B + having difficulty speaking). Health condition C is the condition that exhibits the worst effects.

The basic unit of each risk index was calculated using equation (1) for all industries that are a fixed source of evaporation, as well as for three individual industries (transportation machinery and equipment manufacturing, printing and related, and construction).

$$\text{Basic unit of risk mitigation (BURM)} = \Delta\text{Risk index}/\Delta\text{VOC emission} \quad (1)$$

Here,  $\Delta\text{VOC emission}$  is the amount of change before and after VOC regulations (before – after) of annual VOC emissions in the targeted region of the targeted industries. Actual values from 2000 and 2008 were used as values before and after regulation, respectively.  $\Delta\text{Risk index}$  is the amount of change in each risk index 1)~6) before and after regulation, and each of the substances in index 1)~4) were estimated as follows. The method of estimation for unified risk in 5) and 6) will be explained later.

In relation to the Annual number of early deaths in 1):

$$\begin{aligned} \Delta\text{Risk index} = \\ \text{mortality increment per unit concentration (1/ppb)} \times \Sigma(\Delta\text{concentration}_i \text{ (ppb)} \times \text{annual} \\ \text{number of baseline deaths ( /yr)}) \end{aligned} \quad (2)$$

In relation to the annual cases of carcinogenesis in 2) and the annual cases of subjective symptoms in 3):

$$\begin{aligned} \Delta\text{Risk index} = \\ \text{pathogenesis unit risk per year (1/ppb/yr)} \times \Sigma (\Delta\text{concentration}_i \text{ (ppb)} \times \text{population}_i) \end{aligned} \quad (3)$$

In relation to the annual decrease in rice yield (ozone) in 4):

$$\begin{aligned} \Delta\text{Risk index (kg/yr)} = \text{reduction rate per unit concentration (1/ppb)} \\ \times \Sigma(\Delta\text{concentration}_i \text{ (ppb)} \times \text{annual rice yield}_i \text{ (kg/yr)}) \end{aligned} \quad (4)$$

Here,  $\Delta\text{concentration}_i$  is the difference in concentration estimated by ADMER-PRO, when emissions from 2000 together with VOC emissions from only those appropriate industries from 2008 are input into the model.  $\Sigma$  is the sum for each region. The independent component emissions for VOCs was used for an estimate by treating both years as the same, assuming a common component composition for each emission category (fixed evaporation source of each industry, mobile emission source, households, etc.) and based on the existing values from literature such as the VOC Emission Inventory (Ministry of Environment, 2010). The population and annual number of baseline deaths in each mesh were estimated by approximately the same method as Nakanishi et al. (2009). Annual rice yield in each mesh was estimated from the area of

the "paddy" in each mesh, based on the regression formula (annual rice yield (kg/yr) =  $0.3527 \times \text{area of paddy (m}^2\text{)}$ ), where the relationship between the annual rice yield and total area of the "paddy" at the prefectural level is approximated by a line that passes the origin.

Table 1 organizes the information on the mortality increment per unit concentration of ozone used for the calculation (1/ppb), as well as the hazardous impact annual pathogenic unit risk for other substances, (1/ppb/y) and the rate of reduction per unit concentration of ozone (1/ppb).

Table 1 Information on unit risks, etc., used for calculation

Substance name	Type of impact considered	Mortality increment per unit concentration (1/ppb)	Unit risk of pathogenesis per year (1/ppb/yr) <sup>*1</sup>	Decreased yield per unit concentration (1/ppb) <sup>*2</sup>	Reference
	Early death	2.0E-04			
<b>Ozone</b>	Decreased rice yield			3.4E-03	Nakanishi et al., 2009
<b>Chloroethylene</b>	Cancer		3.2E-07		US EPA, 1995
<b>Dichloromethane</b>	Cancer		5.0E-10		US EPA, 1995
<b>Trichloroethylene</b>	Cancer		3.2E-07		US EPA, 1995
<b>Benzene</b>	Cancer		3.6E-07		US EPA, 1995
<b>1,2-dichloroethane</b>	Cancer		1.5E-06		US EPA, 1995
<b>Acrylonitrile</b>	Cancer		2.1E-06		US EPA, 1995
<b>Toluene</b>	Health condition C <sup>*3</sup>		2.2E-07		Nakanishi and Makino, 2009
<b>Xylene</b>	Health condition C <sup>*3</sup>		4.2E-07		Nakanishi and Makino, 2009

\* 1: Lifetime cancer unit risk is noted (1/μg/m<sup>3</sup>) in the IRIS database. The unit risk value shown here is the value found from having divided the unit risk from IRIS by life years (assumed 70 years), then converting this to concentration unit (at 20°C, 1 atm condition). Additionally, the Specific Risk Assessment Report “Xylene” notes that the pathogenic unit risk per year should be in the unit of (1/mg/m<sup>3</sup>/yr). The unit risk for occurrence of health condition C is the value after converting to a concentration unit (20°C, 1 atm condition).

\* 2: This index was derived by using the growth period average from the 10<sup>th</sup> - 18<sup>th</sup> hour as a concentration. However, the growth period average and annual average for the time period was nearly the same at most full-time monitoring stations. Therefore, in order to derive the Δrisk index, this assessment report uses the national average value from the 10<sup>th</sup> - 18<sup>th</sup> hour as the concentration in Δconcentration.

\* 3: Refer to an earlier footnote for health condition C.

ΔRisk index for each substance for the annual QALY loss in (5), can essentially be estimated by taking the Δrisk index and the number of annual number of cases of hazardous impacts for each of the substances calculated in equations (2) and (3), and then multiplied by the QALY loss of each case of occurrence of hazardous impacts. Here, the QALY loss for each case of pathogenesis was assumed to be 1 year for early death (from EEA: European Environment Agency, 2011), and 10 years for carcinogenesis (Nakanishi et al., 2009). The QALY loss from hazardous impacts by toluene and xylene were calculated also considering the occurrence of health conditions other than C (health conditions A and B, and loss of appetite) as outlined in the Specific Risk Assessment Report “Xylene”<sup>2</sup>. The ΔRisk index of monetary conversion of impacts to humans and

<sup>2</sup> The annual pathogenic unit risk for each health condition as well as the QALY loss for a single pathogenesis was derived from the Specific Risk Assessment Report “Xylene” (Makino & Nakanishi, 2009). The annual pathogenic unit risk for loss of appetite by exposure to xylene cannot be fundamentally derived since the relationship between its concentration and reaction are assumed to be logistic (not assumed to be linear), but was derived here from an approximated linear equation by reasoning that the low dosage part is approximately linear. Also, the annual pathogenic unit risk for loss of appetite by exposure to toluene was assumed to be 0.59 times (=1/1.7) that of exposure to xylene. The value 1.7 is the ratio of probability of pathogenesis by exposure to xylene and toluene, derived by investigating 8 types of common

rice yield in 6) was calculated as follows: The impact on human health was calculated by multiplying the  $\Delta$ risk index of annual QALY loss in (5) with the monetary value for 1 year of lost life expectancy (VOLY: Value of Life Year). VOLY was assumed as 10 million yen/year based on the report by EEA (EEA, 2011). The impact on rice yield was calculated by multiplying the  $\Delta$ risk index of the annual decrease in rice yield in (4) with rice price per kilogram (240 yen/kg, Nakanishi et al., 2009).

#### 2.1.4 Calculated Results for Basic Unit of Risk Mitigation

Table 2 gives the calculated results for each BURM. Table 2 also gives the values for the transportation machinery and equipment industry, which is treated as a case study for analysis in the next section as an example of BURM, but the overview is the same for BURM encompassing all industries. According to the data in table 2, the rate of contribution towards risk mitigation from each of the substances or the sum of all risk mitigation effects is unknown since each of the type of hazardous impacts is different. However, it becomes clear upon viewing the two unified index on the right (QALY and monetary conversion of impact on humans and rice yields). The decrease in ozone concentration had the greatest influence on the human health risk mitigation effect from a basic unit of QALY loss, indicating that the purpose of VOC regulation (to lower photochemical air pollution by ozone, rather than the VOC component concentration itself) was rational. However, because contributions by substances other than ozone is significant at 35%, the basic unit of emission risk mitigation that considers both ozone and VOC components have a high utility value upon assessing the measures for VOC emission mitigation. Next, looking at the basic unit of monetary conversion of impacts on humans and rice yields, the impact on rice yields (73.67 million yen – 2.947 years  $\times$  10 million yen/year = 44.2 million yen) is greater than the impact on humans (2.947 years  $\times$  10 million yen/year = 29.47 million yen), and the contribution rate by ozone is over 80% (6,368/7,367) if you consider the impact on rice yields as well.

Table 2 Calculated results for each type of basic unit of risk mitigation (Transportation machinery and equipment industry, national)

Basic unit of each risk index in Japan (transportation machinery and equipment manufacturing industry)	Number of early deaths (cases /10,000 ton)	Cases of carcinogenesis (cases /10,000 ton)	Cases of subjective symptoms (health condition C) (cases /10,000 ton)	Decreased rice yield (ton /10,000 ton)	QALYs loss (year /10,000 ton)	Monetary conversion of impact on humans and rice yields (10,000 yen /10,000 ton)
Ozone	1.9			184	1.949	6,368
Chloroethylene		0.0000			0.000	0
Dichloromethane		0.0001			0.001	1
Trichloroethylene		0.0217			0.217	217
Benzene		0.0000			0.000	0

subjective symptoms (including loss of appetite) between the two substances.

1,2-dichloroethane		0.0000		0.000	0
Acrylonitrile		0.0000		0.000	0
Toluene			0.17	0.178	178
Xylene			0.58	0.602	602
<b>Total</b>	1.9	0.0218	0.75	2.947	7,368

Note: QALY loss of toluene and xylene is derived by also considering the subjective symptoms from conditions other than health condition C.

A comparison of regions (Kanto, Kinki, Tokai) for BURM revealed a difference of several times among the regions, and the largest was seen in the Kanto region. From this it is evident that even if the same amount of VOC emissions are mitigated, the resulting risk mitigation effect differs largely between regions. When a comparison of BURM was conducted between industries, it was also revealed that there were no significant changes in the basic unit.

## 2.2 Sample Analysis—A Painting Process Case in the Automobile Manufacturing Industry

Paint was targeted for analysis in the trade-off assessment since it is the greatest fixed source of emissions. It was revealed that a negative side exists, such as the increase in energy used for drying as well as for temperature and humidity control, and the cost of improving facilities (drainage treatment, painting) for substitutions from solvent-based to water-based paint in the industrial painting of products such as automobiles and other metal products. Therefore, VOC mitigation measures in the automobile manufacturing industry have been selected for analysis. The basic unit of risk mitigation was used to quantify the risk. Impact, year, area, and substances for the assessment are the same as in the previous section.

### 2.2.1 Mitigation of VOC Emission and Contributions from Mitigation Measures

The data in table 3 show the estimated change over time in VOC emissions for shipping volumes and paint used, by paint type, in the automobile manufacturing industry. For simplicity, the types of paints were grouped into 3 types: “solvent,” “water,” and “solventless.” VOC emissions have reduced by half from 2000 to 2008, but substitution from solvent-based to water-based paint is only 7% by shipping volume ratio, where a decrease in VOC emissions from solvent-based paint was more than double the amount than a decrease in the shipped volume of the solvent-based paint. This suggests that mitigation of solvent content (including decreased solvent use for dilution) in solvent-based paint has a large contribution towards a decrease in VOC emissions.

Table 3 Shipped volume of paint towards automobile manufacturing industry, and VOC emissions from paint used.

(2000, 2008, t/year)

Paint type	Paint shipped				VOC emissions		
	2000		2008		2000	2008	Amount of change
Solvent-based <sup>*1)</sup>	123,204	57.2	104,631	50.1%	99,881	51,517	48,364
Water-based	91,538	42.5%	103,107	49.4%	7,538	2,259	5,280
Non-solvent based	812	0.4%	1,181	0.6%	0	0	-
Total	215,554	100%	208,919	100%	107,420	53,776	53,643
VOC emission inventory <sup>*2)</sup>	215,553		208,920		107,419	54,412	53,007

[Source: Calculated from Ministry of Environment (2010), JPMA (2010), JPMA (2003)]

\*1) Includes lacquer

\*2) There is a difference in the estimated values from this study and the VOC emission inventory values, but this is due to the differences in the significant digits of attainable variables. The analysis was conducted by matching the sum of VOC emissions to the VOC emission inventory.

Measures of VOC emission mitigation subjected for the analysis were: 1. Mitigation of solvent content in paint; 2. substitution of paint from solvent-based to water-based (paint substitution); 3. improving the coating efficiency; and 4. implementing a recovery unit. The data in Table 4 show the estimated rate of contribution towards VOC emission mitigation from each of the measures. When estimating the rate, it was assumed that each measure was to be implemented independently, without other measures being practiced. The rate of contribution to mitigating emission was, from greatest to smallest: 1. 73% for mitigation of solvent content in paint; 2. 19% for paint substitution; 3. 6% for improving the coating efficiency; 4. 2% for implementing a recovery unit.

Table 4 Estimation of contribution for VOC emission mitigation by measures

Measures for VOC emission mitigation	Contributing amount to VOC emission mitigation (t/year)	Contribution rate
① Mitigation of solvent content in paint	38,914	73%
② Substitution from solvent-based to water-based paint	9,887	19%
③ Improving the coating efficiency	2,935	6%
④ Implementing a recovery unit	1,271	2%
Total mitigation	53,007	100%

### **2.2.2 Estimation of Risk Changes and Cost-Effect Analysis**

The cost of gaining 1 year of QALY was estimated by multiplying the estimated amount of VOC emissions per emission mitigation measure with BURM from the “2.1 Basic Unit of Atmospheric Environmental Risk Mitigation by VOC Mitigation,” and then calculating the amount of mitigated risk (human health, rice yield, total). Table 5 summarizes the results. Monetary conversion of decreased risk by decreased rice yield was treated as the decreased amount of cost by subtracting from the mitigation measure cost.

Cost of gaining 1 year of QALY = (increment in cost of measure – increment in rice yield converted to monetary value)/gained QALY (5)

The total gained QALY against VOC emission mitigation between 2000 and 2008 was estimated to be 15.4 years, which makes the monetary terms of gained QALY to be 154 million yen, and the increase in rice yields as 233 million yen. Ranking the measures in terms of a decrease in risk (gained QALY) from highest to lowest, the order was as follows: 1. mitigation of solvent content in paint; 2. paint substitution; 3. Improving the coating efficiency; and 4. Implementing a recovery unit.

The ranking of measures in terms of cost of gaining 1 year of QALY was, from highest to lowest: 2. paint substitution; 4. Implementing a recovery unit; 1. mitigation of solvent content in paint; and 3. Improving the coating efficiency.

This suggests that paint substitution is the least efficient measure. While 3., Improving the coating efficiency, and 4., Implementing a recovery unit are relatively efficient in mitigating risks, they do not contribute greatly to the overall amount of mitigated VOC emissions or risks. The total cost of gaining 1 year of QALY from all measures was estimated to be 900 million yen/year.

Table 5 Amount of change in human health risks for each measure for VOC emission mitigation, and the results of their cost-effect analyses.

(Automobile manufacturing industry, nationwide, changes from 2000 to 2008)

Measures of emission mitigation	Amount of VOC emission mitigation (t/year)	Gained QALY(year/year)	Monetary conversion of rice yield increment (10,000 yen/year)	Cost increment for measures (hundred million yen/year)	Cost of gaining 1 year of QALY (hundred million yen)
① Mitigation of solvent content in paint	38,914	11.3	17,200	89	8
② Paint substitution (solvent-based to water-based)	9,887	2.9	4,370	71	25
③ Improving the coating efficiency	2,935	0.9	1,297	-26	- <sup>a)</sup>
④ Implementing a gas emission processing equipment	1,271	0.4	562	4	10
Total of all measures	53,007	15.4	23,429	221	9

a) The cost of measure per change in unit risk is not calculated since it becomes negative

### 2.2.3 Comparison of Risk Mitigation by Substitution with Water-Based Paint and Changes in Energy Use

Assuming that the increment in consumed power per unit of painted area ( $m^2$ ) is  $0.21 \text{ kWh}/m^2$ , the increase in power used across the country by substituting solvent-based paint to water-based paint is estimated as 16 million kWh/year, and the increase in  $CO_2$  emissions is estimated at  $7,200 \text{ t-CO}_2/\text{year}$ . If the monetary conversion of  $CO_2$  emission risk is  $3,400 \text{ yen}/CO_2\text{-ton}$  based on EEA (2011), then the risk increment by an increase in  $CO_2$  emissions stemming from electrical energy, by substituting solvent-based paint with water-based paint, is estimated as 24 million yen.

The risk increment from an increase in  $CO_2$  emissions from substituting solvent-based paint with water-based paint is 24 million yen/year, which is about the same as the decreased amount of human health risk (29 million yen/year, table 5) and about half of

the decrease in rice yield (44 million yen/year, table 5). However, there is a need to discuss how the assumptions in the estimated and uncertain parameters affect the estimated results.

### 3. Assessment of the Indoor Environment

#### 3.1 Introduction

Ingredients in consumer products have been converted and processes in manufacturing have been changed by the Revised Air Pollution Control Act. The amount of VOCs indoors is therefore expected to decrease. This section uses an indoor exposure assessment tool developed for this project (iAIR), and assesses the impact on the indoor VOC concentration from a substitution of substances between 2000~2008.

#### 3.2 Assessment Targets

##### 3.2.1 Targeted Use and Products

Targeted uses were: printing ink, paint, and adhesives, all of which bring a large quantity of VOC indoors. Targeted products for printing ink were: newspapers, flyers, magazines, and books; targeted products for paints were household paint and targeted products for adhesives were household glues.

##### 3.2.2 Targeted Chemical Substances

As a result of the information collected, a substitution from toluene to ethyl acetate and isopropanol has been assumed for printing ink, as well as a transition from gravure printing to planography. For paint, a substitution from toluene and xylene to petroleum-based hydrocarbons and from solvent-based to water-based paint has been assumed. For adhesives, substitution from toluene to xylene and ethyl acetate and from solvent-based to water-based adhesives has been assumed. With the above in mind, six substances were targeted: toluene, xylene, ethyl acetate, isopropanol, petroleum-based hydrocarbon for paint, and high-boiling-point solvent for printing ink.

Reference values for the six substances above were set, as listed in table 6, after surveying the existing hazardousness assessment, as well as the baseline and reference value settings.

Table 6 List of referenced values for this study

Chemical substance	NOAEL (mg/m <sup>3</sup> )	End point	Product of uncertainty factor
Toluene	30	Impact to nervous system (human)	10
Xylene	39	Incoordination (animals)	500
Isopropanol	220	Kidney disease (animals)	100

Ethyl acetate	225	Decreased reaction against stimulation (animals)	500
Petroleum-based hydrocarbons for paint	1000	Hepatotoxicity (animals)	500
High-boiling-point solvent for printing ink	1000	Hepatotoxicity (animals)	500

### 3.3 Estimation of Indoor VOC Concentration

#### 3.3.1 Method of Estimation

Using an indoor exposure assessment tool developed for this project (iAIR), the exposure concentration was calculated for years 2000, 2005, and 2008, and the difference was defined as the impact of substitution. The assessed area included the whole of Japan, and the calculation was conducted 100,000 times.

The diffusion speed was calculated from the first-order decay constant and initial content. The first-order decay constant was calculated by assuming that the first-order decay model fits the data on diffusion speed taken from the comprehensive search for reports on measurements of domestic products. The decay constant for books, paint, and adhesives was calculated to be  $0.0050 \text{ h}^{-1}$ ,  $0.35 \text{ h}^{-1}$ , and  $0.049 \text{ h}^{-1}$ , respectively.

The actual measurement of concentration of toluene, xylene, ethyl acetate, and isopropanol was used for the outdoor exposure; the total measured concentration of tridecane and tetradecane was used for high-boiling-point solvents by referencing the carbon number of major components; and the total measured concentration for nonane, decane, and undecane was used for petroleum-based hydrocarbons by referencing the carbon number of major components.

#### 3.3.1.2 Calculated Results

Figure 1 shows the estimation by iAIR of the exposure concentration sourced from various uses. The exposure concentration of substituted substances such as toluene decreased with assessed years, while the substituting substances typically increased. However, a decrease in concentration was observed in some of the substituting substances. This stems from the fact that, while the ratio of use of substituted substances decreased as the substituting substances increased, the total use of the solvent nonetheless decreased and thus the amount of substituting substances used also decreased.

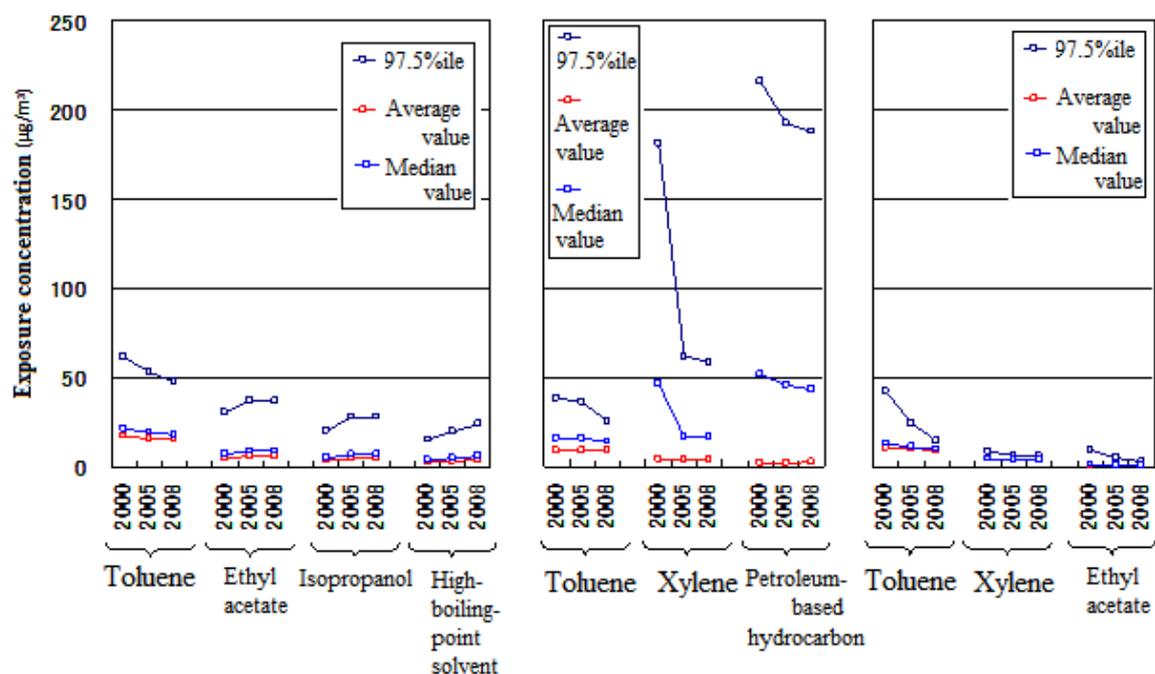


Fig. 1 Changes over time of exposure concentration as estimated by iAIR (from left, printing ink, paint, and adhesive)

Tables 7~9 list the margin of exposure (MOE) calculated from the estimated results of exposure concentration by iAIR. Assuming the appropriate maximum exposure concentration is 97.5th percentile, the MOE was calculated after the NOAEL was removed from this value. The MOE of the substances in each of the uses was greater than the product of uncertainty coefficient, except for in a few, suggesting that the risk of post-substitution is not at a level of serious concern.

Table 7 Exposure margin of chemical substances used in printing ink

Substance	Printing ink			Product of uncertainty factor
	2000	2005	2008	
Toluene	490	560	630	10
Ethyl acetate	7,400	6,000	6,000	500
Isopropanol	11,000	7,800	7,900	100
High-boiling-point solvent	65,000	50,000	42,000	500

Table 8 Exposure margin of chemical substances used in household paint

Substance	Household paint			Product of uncertainty factor
	2000	2005	2008	
Toluene	790	830	1,200	10
Xylene	220	630	670	500
Petroleum-based hydrocarbon	4,600	5,200	5,300	500

Table 9 Exposure margin of chemical substances used in household adhesives

Substance	Household adhesive			Product of uncertainty factor
	2000	2005	2008	
Toluene	700	1,200	2,000	10
Xylene	4,400	5,700	6,400	500
Ethyl acetate	23,000	44,000	67,000	500

#### 4. Summary

In an outdoor, general atmospheric environment, the amount of mitigated human health risk by ozone and VOCs (8 substances) from VOC emission mitigation measures against painting processes in the automobile industry, was estimated using the “basic unit of risk mitigation (transportation machinery and equipment manufacturing industry)” derived from the ADMER-PRO calculation. The national human health risk mitigation by VOC emission mitigation was estimated to be 15.4 years by QALY units, 154 million yen by monetary QALY conversion, while the monetary conversion of increased rice yield was 233 million yen, and the sum of human health and rice yield in monetary terms was 390 million yen.

In the cost-effect analysis per measure, the cost of risk mitigation was, from highest to lowest: 2. paint substitution; 4. implementing gas emission treatment equipment; 1. mitigating the solvent content rate in paint; and 3. Improving the coating efficiency. This indicates that a paint substitution (from solvent-base to water-base) was the most inefficient measure of emission mitigation. As a result of the cost-effectiveness as a total of all measures, the cost of gaining 1 year of QALY was estimated to be 900 million yen/year, and the ratio of decreased risk converted to money against the cost of the measures was 35. The cost-effectiveness of risk mitigation measures is not necessarily high in terms of the cost of gaining one year of QALY, but because the impact of the rice yield risk was greater than that to human health risk, it is also important to consider cost-effectiveness with respect to the rice yield.

A monetary comparison of risk mitigation for human health and rice yield from a substitution of solvent-based paint to water-based paint, and a risk increment by increased energy use (CO<sub>2</sub> emissions) in the painting process using a substitution, suggested a small possibility of a risk trade-off, in which the risk increment of increased CO<sub>2</sub> emissions exceeds the decreased risk towards human health and rice yield by a mitigation of VOC emission.

With respect to the indoor environment, the indoor concentration and exposure concentration were estimated using an indoor exposure assessment tool (iAIR) in relation to three categories (printing ink, paint, adhesives) which are considered to be brought into the indoor environment in large quantities). The exposure concentration of substituted substances such as toluene was suggested to be decreasing with assessed years. However, the exposure concentration of the substituting substances increased in many cases. The MOE calculated from the 97.5th percentile of exposure concentration

for these substances was greater than the product of uncertainty coefficient; indicating there is no serious concern for risks.

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