Calculation of a Toxic Potential Indicator Via Chinese-Language Material Safety Data Sheets

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Keywords:
cleaner production
design for the environment (DFE)
environmental indicator
industrial ecology
material safety data sheet (MSDS)
pollution prevention (P2)

Supplementary material is available on the *JIE* Web site

Summary

This article presents an approach to evaluating the toxic potential for products or materials using Chinese-language material safety data sheets (MSDSs). The toxic potential indicator (TPI) is one of many simple methods used to evaluate the environmental impact of toxins in products and materials. According to actual application experience in Taiwan, difficulties and problems arise in the preliminary implementation of TPI values calculated via Chinese-language MSDSs. Some adjustment techniques combining Chinese vocabulary conversion and unit transformation are proposed in this article to overcome these obstacles. The proposed procedures and evaluated results can serve as a basis for environmentally conscious product design, especially with regard to the choice of materials used in Chinese-speaking countries.

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DOI: 10.1111/j.1530-9290.2009.00126.x

Volume 13, Number 3

Introduction

Industrial development has caused the product manufacturing industry to grow rapidly, and this growth has made an important contribution to Taiwan's economy. Because of the complexity of product manufacturing processes and their waste streams, products may damage the environment and also may injure human health and create social burdens. Thus, immediate environmental assessments on products are imperative. The International Standard ISO 14040 (Life Cycle Assessment [LCA]) series of standards was published in 1997 and is presently available to help identify opportunities to improve the environmental aspects of products and services at various points in their life cycle. In the past, however, people tried to develop non-LCA environmental assessment approaches due to the lack of LCA software databases or due to the complexity of product materials and product manufacturing processes.

There are many small and medium-sized enterprises in Taiwan. When they attempt to utilize LCA tools for product eco-design tasks, they cannot afford to have environmental specialists working for them full-time with LCA tools. Furthermore, many small and medium-sized companies have small product cycles and short production runs. The tools available today are, in general, too complicated and time consuming to be used on these short product cycles. The toxic potential indicator (TPI; Nissen et al. 1997, 1998, 1999; Müller et al. 1999; Middendrof et al. 2000; Schischke et al. 2002a, 2002b), initially developed by the Fraunhofer Institute for Reliability and Microintegration (IZM) in Germany, is one of the simple, non-LCA environmental assessment methods mentioned above. It can directly identify the toxicity of materials by means of material safety data sheets (MSDSs). In addition, the TPI can provide assistance to product designers in the comparison and selection of components or materials with the intention of minimizing hazardous substances for human safety and health. In a sequence of research projects conducted in Taiwan (Yen and Chen 2003; Chen et al. 2005), the main obstacles to the direct application of the IZM TPI method in Taiwan were identified, and some approaches to overcome them were proposed (Yen and Chen 2003). Additionally, modified adjustment modes were presented to fit the method for use as a material assessment tool for the automobile industry in Taiwan (Chen et al. 2005). In this article, we further modify the previous procedures to make it easier for users to carry out the steps required to apply the TPI. Customized applications of the TPI have also been developed by Japanese researchers, with reference to Japanese regulations (Fujino et al. 2005).

Preliminary Application

Most countries require that enterprises keep MSDSs based on their own occupational safety and health regulations. The TPI calculated via an MSDS can be used alone to determine the potential toxicity of materials. We offer some explanations for applications of the TPI and describe the barriers to its use in Taiwan as follows.

MSDSs

Before estimating the TPI of products, one should first understand the properties of the material being evaluated. An MSDS is designed to provide both workers and emergency personnel with the proper procedures for handling or working with a particular substance. It includes information such as physical data (melting point, boiling point, flash point, etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill or leak procedures. These are used specifically if a spill or other accident occurs.

In 1994, the International Standards Organization (ISO) drew up the ISO 11014-1 Standard, which ordered the general layout of an MSDS (ISO 1994). An MSDS is required to provide the chemical product information given under the 16 standard headings shown in table 1, the wording, numbering, and sequence of which have not been altered.

Many countries require the MSDS to be in the native languages of that country; therefore, an MSDS in the United States or United Kingdom must be in English, one in Canada must be available in both English and French, and one in Taiwan must be in Chinese. In general, the manufacturer or distributor is responsible for

Table 1 The standard headings of a material safety data sheet

Section	*Standard heading*
1	Product and company identification
2	Composition/information on ingredients
3	Hazards identification
4	First aid measures
5	Fire-fighting measures
6	Accidental release measures
7	Handling and storage
8	Exposure controls/personal protection
9	Physical and chemical properties
10	Stability and reactivity
11	Toxicological information
12	Ecological information
13	Disposal considerations
14	Transport information
15	Regulatory information
16	Other information

creating the sheet. Each country has its own rules and regulations, so the content of MSDSs in different countries is often not the same. Due to enforcement of regulations, MSDSs are now easy to acquire.

IZM's TPI

This method is a non-life-cycle-oriented approach to generate a numerical indicator for the environmental properties of different materials. It is not as universal or thorough as a full LCA but instead is simpler and faster to use (Nissen et al. 1999). The computational structure of the TPI developed by IZM is based on three components (see figure 1): hazardous substance declarations (*R-phrases*/R-values), allowable workplace concentration (*MAK*), and water pollution classification (*WGK*).

R-phrases is a shortened term for *risk phrases*, as defined in Annex III of European Union (EU) Commission Directive 67/548/EEC: Nature of Special Risks Attributed to Dangerous Substances and Preparations. The list was consolidated and republished in Commission Directive 2001/59/EC (EU 2001), where translations into other EU languages may be found. The *R-phrase* specifies the particular danger of a material. When the TPI is calculated, *R-phrases* are separated if the effect is covered by *MAK* or *WGK* values and are represented as *R_MAK* or *R_WGK*, shown in figure 2.

MAK and *WGK* are based on German legislation. The *MAK* value is the maximum concentration of an exposure material (in the form of gas, vapor, or air-suspended matter) allowable in the workplace—that is, the maximum concentration that, according to the present state of knowledge, generally does not impair the health of workers and does not inconvenience them unduly, not even on repeated and prolonged exposure during a normal 8-hr working day for up to 45 hr a week. On the basis of the German Water Conservation Law, water pollutants are categorized into four classes. Substances are classified as either not hazardous to water or *WGK* 1, 2, or 3.

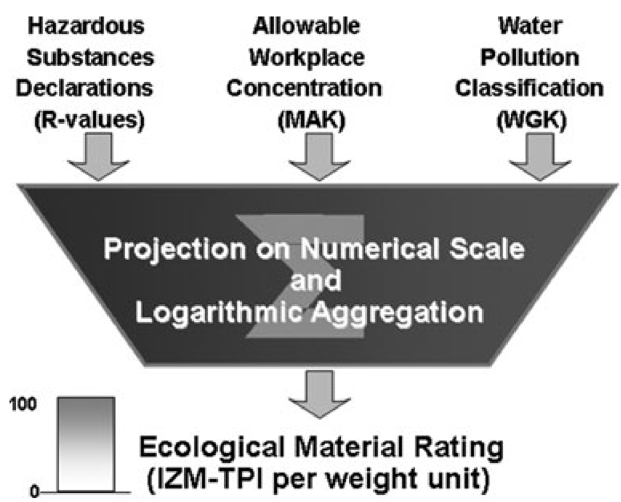

Figure 1 The computational structure of the Fraunhofer Institute for Reliability and Microintegration's (IZM's) toxic potential indicator (TPI; Schischke et al. 2002a).

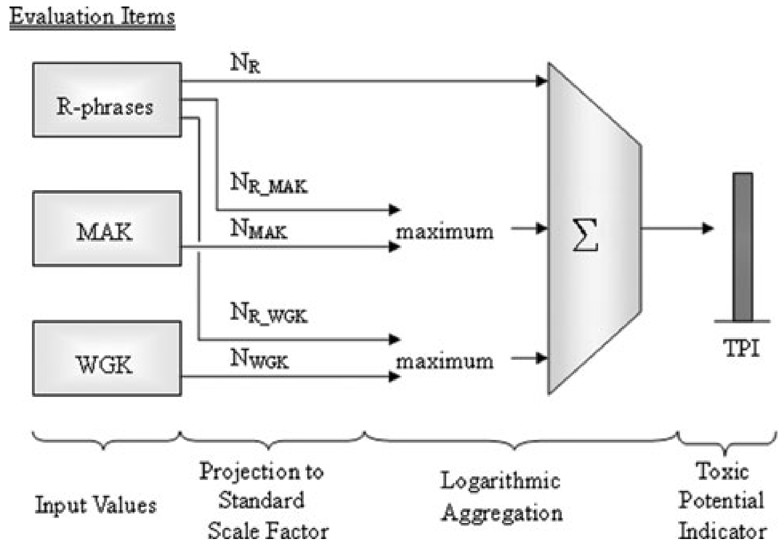

Figure 2 The information flow model of computing the Fraunhofer Institute for Reliability and Microintegration's toxic potential indicator (TPI). *R-phrase* = risk phrase; *MAK* = allowable workplace concentration; *WGK* = water pollution classification; N_R = standard scale factor for *R-phrase*; N_{R_MAK} = standard scale factor for R_MAK; N_{MAK} = standard scale factor for *MAK*; N_{R_WGK} = standard scale factor for R_WGK; N_{WGK} = standard scale factor for *WGK*.

Each input variable is ranked with a standard scale factor—N_R, N_{R_MAK}, N_{R_WGK}, N_{MAK}, or N_{WGK}—from 0 (negligible or zero impact) to 7 (extreme impact). Some *R-phrases* refer to workplace hazards or water hazards, which are already taken into account with *MAKs* and *WGKs*, so they are defined to eliminate these overlaps, as factors N_{R_MAK} or N_{R_WGK}. N_R, N_{R_MAK}, N_{R_WGK}, N_{MAK}, or N_{WGK} identify the numerical scale of each different item's environmental impact from the MSDS. In other words, the ranked data from German MSDSs can be directly and easily read. Then, the use of the following logarithmic aggregation calculation equations (1 through 7) results in the TPI value of a substance from 0 to 100 (Schischke et al. 2002a). The total aggregate TPI values of components or products can be anywhere between zero and infinity.

$$N_{substance} = Aggr\{N_R, \max(N_{MAK}, N_{R\_MAK}), \max(N_{WGK}, N_{R\_WGK})\} \quad (1)$$

$$N_R = \ln\left(\sum_{i=1}^{n} e^{N_{R_i}} - n + 1\right) \quad (2)$$

$$N_{R\_MAK} = \ln\left(\sum_{i=1}^{n} e^{N_{R\_MAK_i}} - n + 1\right) \quad (3)$$

$$N_{R\_WGK} = \ln\left(\sum_{i=1}^{n} e^{N_{R\_WGK_i}} - n + 1\right) \quad (4)$$

where n is, respectively, the number of N_R in equation (2), the number of N_{R_MAK} in equation (3), and the number of N_{R_WGK} in equation (4). The maximum of the standard scale factor for each evaluation item is 7. Therefore, if the result of equation (2), equation (3), or equation (4) is bigger than 7, the value of N_R, N_{R_MAK}, or N_{R_WGK} is defined as 7. The transformation equation from *MAK* into the standard scale factor N_{MAK} is as follows.

$$N_{MAK} = \log\left(\frac{10^4}{MAK}\right) \quad (5)$$

The value of N_{WGK}, according to *WGK* 1, 2, and 3, respectively, equals 3, 5, and 7. The actual mathematic form of equation (1) is expressed as equation (6).

$$N_{substance} = Aggr\{N_1 \ldots N_n\} = \ln\left(\sum_{i=1}^{n} e^{N_i} - n + 1\right) \quad (6)$$

where n is from 0 to 3. The final TPI value of a material is derived from equation (7) by division

Table 2 Comparison between Germany and Taiwan (Yen and Chen 2003)

	Country	
Item	*Germany*	*Taiwan*
R-phrases	Based on European legislation (Directive 2001/59/EC for the classification of dangerous substances)	Refers to the 3rd section (hazardous identification), the 10th section (stability and reactivity), and the 11th section (toxicological information) of an MSDS
	Directly quoted from the *R-phrases* in the 15th section (regulatory information) of an MSDS	Integrates the above information, then refers to Directive 2001/59/EC for the classification of a dangerous substance
MAK	Based on German legislation	Directly quoted from the eighth section (exposure controls/personal protection) of an MSDS
	Directly cited from the value in the eighth section (exposure controls/ personal protection) of an MSDS	Refers to the regulations that include the threshold limit value (TLV) in Taiwan (CLA 2003)
		References worldwide threshold limit values, such as the American Conference of Governmental Industrial Hygienists (ACGIH) or *MAK* (Germany)
WGK	Based on German legislation	Refers to the 12th section (ecological information) and the 13th section (disposal considerations) of an MSDS
	Directly quoted from the *WGK* value in the 15th section (regulatory information) or the 12th section (ecological information) of an MSDS	Integrates the above information, then identifies the *WGK* value

Note: *R-phrase* = risk phrase; MSDS = material safety data sheet; *MAK* = allowable workplace concentration; *WGK* = water pollution classification.

via the scaling factor.

$$TPI_{substance} = (e^{N_{substance}} - 1)/\text{scaling factor} = (e^{N_{substance}} - 1)/32.869 \quad (7)$$

where the scaling factor is calculated on the basis of the assumption of the maximum impact $N_R = N_{MAK}$ (or N_{R_MAK}) $= N_{WGK}$ (or N_{R_WGK}) $= 7$.

A TPI value of zero means that a material, such as silicon or silicon dioxide, has very little environmental influence. Conversely, a result of 100 in the TPI value indicates that a material has a very large environmental impact.

By using the above procedures, we can obtain the TPI values for materials. The TPI value for one component is the summation of the product of the TPI value for the material and the mass (in milligrams [mg]) of that material, as shown in equation (8).

$$TPI_{component} = \sum [TPI_{substance} \times m_{substance}] \quad (8)$$

The TPI for a whole product is given by

$$TPI_{product} = \sum [TPI_{component}] \quad (9)$$

If the compositions of the components are calculated, the product's TPI value can be determined very quickly.

The Obstacles to Preliminary Application in Taiwan

When TPI values with Chinese-language MSDS data available in Taiwan were computed according to the German TPI calculation procedure, the main difficulties and problems were incorrect data and lack of useful data. The sources of the environmental properties for computing TPI values in Taiwan and Germany are somewhat different, although both of them draw chiefly on MSDSs. The environmental properties of the different materials are rated according to legal classifications in Germany, so *R-phrases* and *WGK* listed in the 15th section of an MSDS conforming to German regulations can be found directly, but they cannot be found in Chinese-language MSDSs on the whole. A comparison between source locations and descriptions of MSDS data from Germany and Taiwan leading to TPI values is shown in table 2.

During initial attempts to calculate TPI values in Taiwan, we usually obtained specific information about a material's environmental properties by referring to several sections of an MSDS. MSDSs are written in the Chinese language or are translated from foreign languages into the Chinese language in Taiwan. Therefore, misinterpretation of information may cause an incorrect result with respect to the numerical scale for a specific material's environmental impact. Data collected by different people to calculate TPI values quoting from the same Chinese-language MSDS may disagree and lead to different standard scale factors, which results in different TPI values for the same material. Another problem is that most MSDSs in Taiwan do not have *WGK* values, and it is not easy for an evaluator to correctly identify a *WGK* value referring to German regulations. Furthermore, some units of allowable workplace concentration are parts per million (ppm), not milligrams per cubic meter (mg/m^3), in Taiwan. As a result of all these factors, it is necessary to make some customizations regarding the application of TPI in Taiwan.

Calculating TPI in Taiwan

The new applications of the TPI in Taiwan are quite different from those used in Germany. The modified calculating procedures are described in detail as follows.

Calculating Targets

The toxicity of materials must be considered, including those designated as toxic chemical substances by Taiwan's Environmental Protection Administration (EPA) or as dangerous and hazardous substances by the Council of Labor Affairs of Taiwan. Additionally, other substances that may cause environmental impact or be harmful to human safety and health have to be taken into account.

Environmental Properties Source

On the basis of Taiwan's labor safety and health legislation, employers must label dangerous and hazardous materials with necessary precautionary safety and health warnings, and MSDSs are essential to achieve this. Since the beginning of 2001, Taiwan's government has enforced a new MSDS legal format, which has 16 sections, according to the ISO 11014-1 Standard for dangerous and hazardous materials. Unlike Germany, in Taiwan the environmental properties of different materials are not ranked according to legal classifications, so they cannot be directly found in Chinese-language MSDSs. In this article, we propose that the three evaluation items used to calculate TPI values be determined by the following modified techniques.

Hazardous Substance Declarations

The EU requires that *R-phrases* appear on each label and safety data sheet for hazardous chemicals, so *R-phrases* are listed in the 15th section (regulatory information) of an MSDS in EU countries. Because of the lack of compulsory legislation in Taiwan, users of the Chinese-language MSDS usually obtain information referring to several sections of an MSDS. According to the ISO 11014-1 Standard, the 3rd section (hazards identification) of an MSDS shall clearly and briefly summarize the most important hazards and effects of a material. This section includes adverse human health effects, environmental effects, physical and chemical hazards, and specific hazards. In Taiwan, a Chinese-language MSDS usually has the same four subsections in the 3rd section, but the content descriptions of the last two subsections are not clearly defined, so we refer to the definitions of *R-phrases* (EU 2001) and divide them into three categories. In addition, we group the Chinese vocabulary descriptions, which are translated from *R-phrases*, according to their attributes and the values of standard scale factors and then add some Chinese phrases that appear frequently in Chinese-language MSDSs in every classification. The classification modes make selection of the most appropriate hazardous substance classifications easier and faster. The standard scale factor for each classification is ranked from 1 to 7, with reference to German

Table 3 Category 1: Adverse health effects and standard scale factors

Hazardous substance classification	*Code*	*Description*	N_R *or* N_{R_MAK}
Inhalation	A01	Causes slight discomfort, irritating to respiratory system, causes sensitization, or vapors may cause drowsiness and dizziness	$2_{(R\_MAK)}$
	A02	Harmful	$3_{(R\_MAK)}$
	A03	Toxic	$5_{(R\_MAK)}$
	A04	Very toxic, causes death or may cause cancer	$7_{(R\_MAK)}$
Skin contact	A05	Causes slight discomfort, irritation, or sensitization; repeated exposure may cause skin dryness or cracking	2
	A06	Harmful, causes burns or frostbite	3
	A07	Toxic, corrosive, or causes severe burns	5
	A08	Very toxic or causes death	7
Eye	A09	Irritation or discomfort	2
	A10	Risk of serious damage to eyes or eye tissue	4
Ingestion	A11	Harmful or causes stomach and intestinal discomfort	2 2
	A12	May cause lung damage	3
	A13	Toxic or harmful to organs	4
	A14	Very toxic or causes death	6
Carcinogen	A15	Limited evidence	$6_{(R\_MAK)}$
	A16	May cause cancer	$7_{(R\_MAK)}$
Baby, embryo, or heredity	A17	May cause harm to breastfed babies or possible risk of harm to the unborn child	4
	A18	May cause harm to the unborn child or or may cause heritable genetic damage	6
Chronic	A05	Repeated exposure may cause skin dryness or cracking	2
	A19	Danger of cumulative effects	4
	A20	Serious damage to health by prolonged exposure	5
Irreversibility	A21	Possible risk of irreversible effects	5
	A22	Danger of very serious irreversible effects	6

Note: N_R = standard scale factor for *R-phrase*; N_{R_MAK} = standard scale factor for *R_MAK*.

TPIs. The classifications are divided into three categories to facilitate their use. These categories and their standard scale factors are shown in table 3, table 4, and table 5, and these tables are shown in the Chinese language in Taiwan in Tables S-1, S-2, and S-3 in the Supplementary Material on the Web.

Tables S-1 through S-3 provide a systematic sequence that can allow different users of Chinese-language MSDSs to immediately have consistency for hazardous declaration data.

Allowable Workplace Concentration

The 8-hr time weighted average (*TWA*) refers to a concentration of an airborne toxic material that has been averaged over an 8-hr working day. The permissible exposure limit–*TWA* (PEL-*TWA*) is the concentration for a normal 8-hr working day, 40 hr per week, to which all workers may be exposed without adverse health effect. The value from the control parameters in the eighth section (exposure controls/personal protection) of a Chinese-language MSDS can be found in Taiwan. The transformation equation from *TWA* into the standard scale factor, if the unit of *TWA* is milligrams per cubic meter, is as follows.

$$N_{MAK} = \log\left(\frac{10^4}{TWA}\right) \tag{10}$$

Table 4 Category 2: Environmental effects and standard scale factors

Hazardous substance classification	*Code*	*Description*	N_R *or* N_{R_WGK}
Organisms	B01	Toxic to bees	3
	B02	Toxic to flora, fauna, or soil organisms	4
	B03	Harmful to aquatic organisms	$4_{(R\_WGK)}$
	B04	Toxic to aquatic organisms	$5_{(R\_WGK)}$
	B05	Very toxic to aquatic organisms	$6_{(R\_WGK)}$
Soil	B02	Toxic to soil organisms	4
	B06	Possible risk of impaired fertility	4
	B07	May impair fertility	6
Environment	B08	May cause long-term adverse effects in the aquatic environment	$4_{(R\_WGK)}$
	B09	May cause long-term adverse effects in the environment	4
	B10	Dangerous for the ozone layer	7

Note: N_R = standard scale factor for *R-phrase*; N_{R_WGK} = standard scale factor for *R_WGK*.

Because there are two kinds of units for allowable workplace concentrations in Taiwan, if the unit of *TWA* in an MSDS is parts per million, then we should first transform it into a specified unit before performing the calculation shown in equation (10), and we can derive equation (11) from the unit-transforming operation.

$$C_m = \frac{C_p \times M}{V} \tag{11}$$

where C_m and C_p both are the allowable workplace concentrations, but the unit of C_m is

Table 5 Category 3: Physical and chemical effects and specific hazards and standard scale factors

Hazardous substance classification	*Code*	*Description*	N_R
Contact with water	C01	Reacts violently	1
	C02	Liberates extremely flammable gases	3
	C03	Liberates toxic gas	4
Contact with acids	C04	Liberates toxic gas	3
	C05	Liberates very toxic gas	5
Fire	C06	Contact with combustible material may cause fire	1
	C07	May cause fire	2
Flammability	C08	Flammable	1
	C09	Highly flammable in use or forms flammable vapor—air mixture	2
	C02	Contact with water liberates extremely flammable gases	3
	C10	Extremely flammable or spontaneously flammable in air	4
Explosion	C11	Heating may cause an explosion	1
	C12	Forms very sensitive explosive metallic compounds, vapor—air mixture, or peroxides	2
	C13	Explosive with or without contact with air or when mixed with combustible or oxidizing material	2
	C14	Explosive when dry	3
	C15	Risk of explosion by shock, friction, fire, or other sources of ignition	3
	C16	Extreme risk of explosion by shock, friction, fire, or other sources of ignition	4

Note: N_R = standard scale factor for *R-phrase*.

Table 6 Water pollution and standard scale factors

Description	N_{WGK}
No hazard to water	0
Low hazard to water	3
Hazard to water	5
Severe hazard to water	7

Note: N_{WGK} = standard scale factor for *WGK*.

milligrams per cubic meter and the unit of C_p is parts per million; *M* is the molecular weight; and *V* is the molecular volume. Usually, we assume that the molecular volume is 24.45 L under the normal temperature (25°C) and the normal pressure condition (1 atmosphere); therefore, 24.45 substitutes for *V*, and we can arrive at equation (12).

$$C_m = \frac{C_p \times M}{24.45} \qquad (12)$$

In Taiwan, in instances where the unit of *TWA* is in parts per million, we can overcome the occasional problem of having two different units of *TWA* by using equation (12) and then calculating a standard scale factor, N_{MAK}, for this evaluation item.

Water Pollution Classification

This evaluation item is a classification for materials that discharge into water, whether they can cause pollution or not. On the basis of their harmful influences on water, we can divide them into four categories, shown in table 6.

Referring to the descriptions in the 12th section (ecological information) and the 13th section (disposal considerations) of a Chinese-language MSDS, we can determine a standard scale factor for this evaluation item, according to table 6.

Case Study

The method for evaluating the toxic potential of products described in this article is illustrated with a case study of an automobile tire. The components and weight percentages of the automobile tire are presented in table 7, and the compositions and weight percentages of the filler that is one of the automobile tire components are listed in table 8.

First, after screening the Chinese-language MSDS for silicon dioxide used in this study and using the hazardous substance declarations referenced in table 3, we can obtain its environmental properties, as shown in table 9.

Table 7 Components and weight percentages of automobile tire

Component	*Weight %*
Natural rubber	24.85
Synthetic rubber	23.53
Filler	25.67
Process aids	6.49
Resin	0.79
Adhesive	0.23
Antioxidant	1.37
Vulcanization accelerator	1.92
Polyester	3.45
Nylon	0.32
Bead wire	4.71
Steel belt	6.67
Total weight (kg)	11.752

Using values shown in table 9, we can calculate the TPI value of silicon dioxide as follows using equations (10), (1), (6), and (7), respectively.

$$N_{MAK} = \log\left(\frac{10^4}{TWA}\right) = \log\left[\frac{10^4}{4}\right] = 3.4$$

$$\begin{aligned} N_{Silicon\ dioxide} &= Aggr\,\{N_R, \max(N_{MAK}, N_{R\_MAK}),\\ &\quad \max(N_{WGK}, N_{R\_WGK})\}\\ &= Aggr\,\{2, \max(3.4, -), \max(-, -)\} \end{aligned}$$

$$\begin{aligned} N_{\text{Silicon dioxide}} &= \ln\left(\sum_{i=1}^{n} e^{N_i} - n + 1\right)\\ &= \ln\left[e^{N_R} + e^{N_{MAK}} - 2 + 1\right]\\ &= \ln(e^2 + e^{3.4} - 2 + 1) = 3.59 \end{aligned}$$

$$\begin{aligned} TPI_{\text{Silicon dioxide}} &= (e^{N_{\text{Silicon dioxide}}} - 1)/32.869\\ &= (e^{3.59} - 1)/32.869 = 1.07 \end{aligned}$$

Second, in accordance with the Chinese-language MSDS for carbon black used in this study and using the hazardous substance

Table 8 Compositions and weight percentages of filler

Material	*CAS No.*	*Weight %*
Silicon dioxide	7631-86-9	0.43
Carbon black	1333-84-4	99.57

Note: CAS No. = chemical abstracts service registry number.

Table 9 Evaluation results for silicon dioxide

Evaluation item	*MSDS contents*	*Result*
Hazardous substance declarations	Irritating to eyes	A09 ($N_R = 2$)
Allowable workplace concentration	*TWA*: 4 mg/m^3	4 mg/m^3
Water pollution classification	None	

Note: MSDS = material substance data sheet; *TWA* = time-weighted average.

declarations referenced in table 3, we could obtain the results shown in table 10.

Using values shown in table 10, we can calculate the TPI value of carbon black as follows using equations (3), (10), (1), (6), and (7), respectively.

$$N_{R\_MAK} = \ln\left(\sum_{i=1}^{n} e^{N_{R\_MAK_i}} - n + 1\right)$$
$$= \ln\left(e^{N_{R\_MAK_1}} + e^{N_{R\_MAK_2}} - 2 + 1\right)$$
$$= \ln(e^2 + e^7 - 2 + 1)$$
$$= 7.01 >, \text{ then take } 7.$$

$$N_{MAK} = \log\left(\frac{10^4}{TWA}\right) = \log\left[\frac{10^4}{3.5}\right] = 3.46$$

$$N_{Carbon\ black}$$
$$= Aggr\left\{N_R, \max\left(N_{MAK}, N_{R\_MAK}\right), \max\left(N_{WGK}, N_{R\_WGK}\right)\right\}$$
$$= Aggr\left\{2, \max(3.46, 7), \max(-, -)\right\}$$

$$N_{Carbon\ black} = \ln\left(\sum_{i=1}^{n} e^{N_i} - n + 1\right)$$
$$= \ln\left(e^{N_R} + e^{N_{R\_MAK}} - 2 + 1\right)$$
$$= \ln(e^2 + e^7 - 2 + 1) = 7.01$$

$$TPI_{Carbon\ black} = (e^{N_{Carbon\ black}} - 1)/32.869$$
$$= (e^{7.01} - 1)/32.869 = 33.66$$

We can calculate the TPI value of the filler by using equation (8) as follows.

$$TPI_{\text{Filler}} = [TPI_{\text{Silicon dioxide}} \times m_{\text{Silicon dioxide}}]$$
$$+ [TPI_{\text{Carbon black}} \times m_{\text{Carbon black}}]$$
$$= [1.07 \times (11.752 \times 10^6 \times 25.67\% \times 0.43\%)]$$
$$+ [33.66 \times (11.752 \times 10^6 \times 25.67\% \times 99.57\%)]$$
$$= 101120657.9$$

Repeating the above steps for the other components of the tire, we can calculate the TPI values, which are shown in table 11.

After we compute the TPI values of all the components, we can obtain the TPI value of the automobile tire from totals derived from equation (9). In this specific case, we found that the filler played a key role in the TPI value of the automobile tire. If the goal is to reduce the potential toxicity of this product, the filler should be the main target. Additionally, the method used herein provides an easy and feasible approach for product designers to use when they compare and select components or materials with the intention of minimizing hazardous substances.

Table 10 Impact evaluation for carbon black

Evaluation item	*MSDS contents*	*Result*
Hazardous substance declarations	Cause cough by inhalation	A01 ($N_{R\_MAK} = 2$)
	Cause teardrops from eyes	A09 ($N_R = 2$)
	May cause cancer	A16 ($N_{R\_MAK} = 7$)
Allowable workplace concentration	*TWA*: 3.5 mg/m^3	3.5 mg/m^3
Water pollution classification	None	

Note: MSDS = material safety data sheet; N_{R_MAK} = standard scale factor for *R_MAK*; N_R = standard scale factor for *R-phrase*; *TWA* = time-weighted average.

Table 11 Tire component toxic potential indicator (TPI) values

Component	*TPI*
Natural rubber	0
Synthetic rubber	2,076,460
Filler	101,120,658
Process aids	1,680,441
Resin	333,651
Adhesive	18,861
Antioxidant	813,365
Vulcanization accelerator	1,740,376
Polyester	2,339,411
Nylon	37,606
Bead wire	2,625,526
Steel belt	4,039,483
Total amount	116,825,838

Conclusions

There are many small and medium-sized enterprises in Taiwan, and they have many small product cycles and short production runs. There may be no toxicologists or environmental specialists in the companies' product design divisions due to the cost of such services. These enterprises need an easy-to-use and time-efficient tool for environmentally conscious design, and the TPI is sufficient to meet their needs. It is not a traditional LCA tool that needs a large quantity of inventory data, and MSDSs are sufficient to establish the indicator of toxicity. On the whole, the TPI, based on applicable MSDSs, is a simple and direct tool to help product designers compare and select components and materials to reduce the potential toxicity of products.

In this article, we have proposed some adjusting techniques to overcome the problems of the application of this methodology in Taiwan. It has been shown that the TPI method, properly customized, is applicable to the regulations of other countries as well. This modified concept not only can be applied to Chinese-speaking countries but can also be extended to other countries, especially non-English-speaking countries, when used in compliance with their own languages, vocabularies, and regulations.

Acknowledgements

This research was sponsored by the Ford Lio Ho Motor Co. Ltd., Taiwan. We also acknowledge Mr. Karsten Schischke of the Fraunhofer Institute for Reliability and Microintegration for the explanation of the computational structure of toxic potential indicator methodology.

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Supplementary Material

Additional Supplementary Material in the form of an appendix may be found in the online version of this article:

Appendix S1.

This appendix shows the three categories of classifications, as well as their standard scale factors, used in constructing the toxic potential indicator (TPI) in Chinese (tables S1 through S3).

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