Research on the Structure and Application of Fuzzy Environmental Impact Assessment Model

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Abstract

Any business activities may have impact on environment to a certain extent. Enterprises must find appropriate approaches to measure the impact on these environmental aspects, which can be used as the basis to direct enterprises' efforts to improve the environmental impact. The method used to evaluate significant factors in life cycle assessment standards is the one most commonly used by enterprises in general to measure environmental impact. By this method, the decisive factors of each environmental aspect are given scores according to the preset scoring standard of the organization. The scores are added up for each aspect and ranked to assess major environmental aspects. The drawback of this assessment method, that is, it ignores the degree to which each of these factors affects the environment, results in poor credibility. Therefore, this study attempts to solve some qualitative problems by applying to fuzzy theory, in particular, by identifying appropriate fuzzy numbers through fuzzy sets and membership function. Moreover, the study seeks to obtain a crisp value in the process of defuzzification in order to make up for the shortfall of the original method in dealing with relative weight of decisive factors and thus increase its applicability and credibility. The department of light production of an electronics company is used as an example in this study to measure environmental aspects by employing both the traditional significant factor method and the fuzzy environmental impact assessment model proposed in this study. Based on verification and comparison of results, the model proposed in this study is more feasible as it reduces partiality in decision-making by taking the relative weights of decisive factors into consideration.

Key Words: Life Cycle Assessment, Environmental Aspects, Fuzzy Theory

1. Introduction

Life Cycle Assessment (LCA) usually includes four phases [6], all of which have corresponding standards in international standards by International Organization for Standardization. They are ISO 14040 Principles and Structure, ISO 14041 Goal and Scope Definition, and Inventory Analysis, ISO 14042 Environmental Impact Assessment, and ISO 14043 Analysis Results Interpretation. The method of assessment is currently under development. It entails the following three major steps: (1) to collect and summarize an input and output inventory list relating to this product system; (2) to assess the potential environmental impact of these inputs and outputs; and (3) to interpret the results of inventory analysis and impact assessment relating to operational goals. According to ISO 14040 and ISO 14041, the implementation of life cycle assessment can be divided into six steps, that is, the iterative process stressed in ISO international standards. The six steps [5] include: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, result interpretation, verification and investigation, and reporting results. ISO 14040 can be used to develop life cycle assessment standards. Life cycle assessment has four major steps, as illustrated below:

1. Goal and Scope Definition: The operational goal and scope of life cycle assessment should clearly explain the expected applications and the reason for implementing this operation.
2. Life Cycle Inventory Analysis: This step includes data collection and computation procedure to quantify the inputs and outputs of a product system. These inputs and outputs must include resource utilization of the system, as well as disposal of air, water, and land.
3. Life Cycle Impact Assessment: At this step, the potential environmental impact information is added to clarify the data derived from inventory analysis. The converted inventory analysis results based on impact assessment communicate a more meaningful message to decision-makers and are easier to be taken into account in management decisions. The structure of impact assessment consists of three primary steps. (1) Classification: that is, to classify environmental impact. According to U.S. Society of Environmental Toxicology and Chemical (SETAC), environmental impact can be classified by four categories of ecological health, human health, resource exhaustion, and social benefits. (2) Characterization: that is, to select a method to measure impact. The specific assessment tool is applied to the analysis of potential impact that different loads or elements disposed have on various environmental problems. (3) Valuation: that is, to give

relative weight to different types of impact and obtain an integrated impact index, which will enable decision-makers to take all environmental impact into consideration at one time in decision-making process.

4. Result Interpretation: This is the step in life cycle assessment that combines the results observed in life cycle inventory analysis and life cycle impact assessment, or the step in life cycle inventory operation that integrates the observed results from inventory analysis with goal and scope definition.

When implementing an operation, product, or service, enterprises will certainly create more or less impact on environment. Significant factor method is most commonly used by today's average manufacturers to assess environmental impact. This method considers the decisive factors of environmental aspects such as frequency of impact, probability of impact, and gravity of impact etc. The total score for each aspect is obtained by summing up the scores given to decisive factors according to the preset scoring standard of the organization and then ranked to provide an indicator of the degree of impact. The degree of impact that decisive factors have is ignored in this method. The purpose of the fuzzy environmental impact assessment model established in this study is to provide a method of semantic assessment that measures the degree of impact that various environmental aspects have on environment by fuzzy theory.

2. Fuzzy Theory

2.1 Fuzzy Set and System Definition

2.1.1 Fuzzy Empty Set and Universal Set

In the domain, the corresponding membership function $\mu_A(x)$ of all the elements x equals 0, i.e., $\mu_A(x) = 0$. In other words, the set that does have any support is called fuzzy empty set. If the corresponding membership function $\mu_A(x)$ of all the elements x equals 1, i.e., $\mu_A(x) = 1$, then the set is called fuzzy universal set [2].

2.1.2 Intersection of Fuzzy Sets

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)) = \mu_A(x) \wedge \mu_B(x) \quad (1)$$

2.1.3 Union of Fuzzy Sets

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) = \mu_A(x) \vee \mu_B(x) \quad (2)$$

2.1.4 Complement Set of Fuzzy Sets

$$\mu_A(x) = 1 - \mu_A(x) \tag{3}$$

The basic structure of general fuzzy systems (also called fuzzy inference systems) is illustrated in Figure 1.

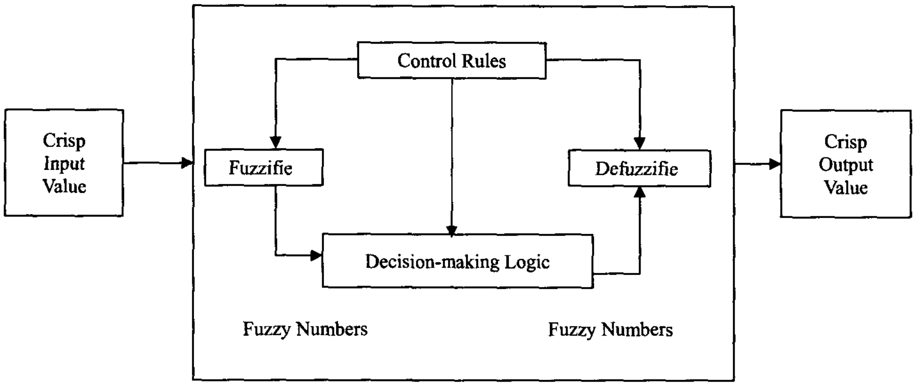

Figure 1. Basic Structure of Fuzzy Systems [1]

1. Fuzzification: It measures the value of input variable, and converts crisp input value to semantic value applicable to fuzzy systems to complete the job of fuzzification.
2. Design of Control Rules and Fuzzy Inference: Semantic control rules are usually transformed from operators' experience and experts' knowledge. Fuzzy inference calculates fuzzy output with given fuzzy logic operation and fuzzy input value (that is, completes the calculation of fuzzy rules).
3. Defuzzification: It converts fuzzy output value to actual crisp value.

In developing fuzzy environmental impact assessment model, first of all, the fuzzy membership function of all decision factors is constructed; second, triangular membership function is used as the basis in fuzzification to determine the degree of membership; third, the degree of membership of risks is produced by establishing rule base and selecting appropriate fuzzy inference; and last, a crisp value, i.e. the prioritization list of risks for improvement, is obtained through defuzzification. The fuzzy environmental impact assessment model in this research is constructed by following the steps below: (1) determination of decision factors; (2) development of membership functions; (3) fuzzification of inputs; (4) establishment of rule base; (5) fuzzy inference; and (6) defuzzification.

2.2 Determination of Decision Factors and Development of Membership Functions

First of all, frequency of occurrence, probability of impact, and gravity are used as the decision factors in assessing the impact that the disposal of waste gas and water has on environment. Dissolvability, recyclability, and output are the decision factors in assessing the impact that the solid wastes have on environment. The relevant definitions are explained as follows:

2.2.1 Disposal of Waste Gas and Water

Frequency of Occurrence: should assess the interval of occurrences.

Probability of Impact: that is, the probability of environmental impact caused by loss of control at each occurrence.

Gravity: measures the severity of environmental impact or the degree of impact at each occurrence.

2.2.2 Solid Wastes

Dissolvability: assesses whether wastes can be dissolved.

Recyclability: assesses whether wastes can be recycled.

Output: assesses the quantity of each waste.

Membership function is built case by case, with no fixed rule or universal theorem or formula. Besides recognition by individual viewpoints, membership function can also be based on statistical methods or experts' opinions. Regardless of which approach is taken, the only common rule that must be abided by is that it should be reasonable and acceptable and should encourage continuous study and accumulation of experience to help more completely and objectively build membership function. The followings are the fuzzy membership functions built on decision factors, as illustrated in Tables 1 to 6.

Table 1. Semantic Assessment Criteria for Frequency of Occurrence

Score	Frequency of Occurrence	Meaning
1	Extremely Low	Never occurs
2	Low	Rarely occurs
3	Medium	Occasionally occurs
4	High	Often occurs
5	Extremely High	Consistently occurs

Table 2. Semantic Assessment Criteria for Probability of Impact

Score	Probability of Impact	Meaning
1	Extremely Low	Even if it occurs, it will not go out of control to cause any loss or impact.
2	Low	A little reinforcement of control can prevent any loss or impact.
3	Medium	Loss of control occurs occasionally, but in most cases, control can be reinforced to avoid any loss or impact.
4	High	Loss of control occurs often, which causes loss and impact.
5	Extremely High	Loss of control occurs consistently, which causes loss and impact.

Table 3. Semantic Assessment Criteria for Gravity

Score	Gravity	Meaning
1	Extremely Low	The impacted area is quite small and limited to a small number of employees positioned in the neighborhood of disposal location.
2	Low	The impacted area is limited to many employees within the factory.
3	Medium	The impacted area expands outside the factory and environment is slightly impacted.
4	High	The impacted area expands outside the factory and environment is seriously impacted.
5	Extremely High	The impacted area is huge and the impact is significant and widespread.

Table 4. Semantic Assessment Criteria for Dissolvability

Score	Dissolvability	Meaning
1	Extremely Low	Completely dissolvable
2	Low	Primarily dissolvable
3	Medium	Partially dissolvable
4	High	A little dissolvable
5	Extremely High	Not dissolvable

Table 5. Semantic Assessment Criteria for Recyclability

Score	Recyclability	Meaning
1	Extremely Low	Can be recycled and reused directly before any processing procedure
2	Low	Can be recycled and reused after simple processing procedure
3	Medium	Can be recycled and reused after processing procedure
4	High	Can be recycled and reused only after difficult or complicated processing procedure
5	Extremely High	Cannot be recycled or reused

Table 6. Semantic Assessment Criteria for Output

Score	Output	Meaning
1	Extremely Low	A very small quantity
2	Low	A small quantity
3	Medium	A fair quantity
4	High	A large quantity
5	Extremely High	A very large quantity

Based on semantic variables and the descriptions in Tables 1 to 6, the fuzzy set of frequency of occurrence, gravity, probability of impact, and output quantity can be derived.

2.3 Fuzzification and Rule Base Theory

The purpose of fuzzification is to use membership function to generate a measure between 0 and 1, convert crisp input values to semantic variables, and transform the inputs of frequency of occurrence, probability of impact, and gravity to a format acceptable to the premise of rule base. The inputs mentioned above can be quantitative or qualitative. The user must do the assessment first and give appropriate degree of membership to fuzzy sets. Membership function has different types such as S-function, Π-function, Z-function, and exponential function. In addition, triangular, trapezoidal, and bell-shaped membership functions are most commonly seen. This study primarily applies to triangular membership function (as shown in Figure 2). Formula [4] is described below.

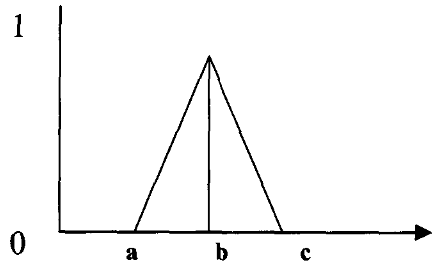

Figure 2. Triangular Fuzzy Numbers

$$\mu_A(x) = \begin{cases} 0 & \text{for } x < a \\ (x-a)/(b-a) & \text{for } a \quad x < b \\ 1 & \text{for } x = b \\ (c-x)/(c-b) & \text{for } b < x \quad c \\ 0 & \text{for } x > c \end{cases} \qquad (4)$$

Rule base consists of a series of control rules. In designing rule base, the first thing that requires caution is defining input and output variables or identifying appropriate variables according to the conditions given by the system. Design of control rules can start as soon as variables to be used are determined. The generally-applied methods include [3]:

1. Based on experts' experience and knowledge: This method interviews experts, summarizes their experience and knowledge, and converts them to simple conditional sentences in description. In the process of acquiring knowledge, we can request experts write down opinions and experience. Oral description works too as fuzzy control itself is implemented by oral command.
2. Determined by the operator's actions: The control to some degree is involved. No so-called experts. However, we can find some rules of control by observing the operator.
3. Based on the fuzzy model of the subject under control: Some subjects under control may have different responses to different inputs, based on which, some systematic behaviors can be summarized and in turn fuzzy control rules can be identified.
4. Based on self-organization, adjustment, and learning: In existing control field, the popular ways of learning include reinforcement learning, neural network, and genetic algorithm. The rules generated by learning method can also be divided into two categories, one is to adjust existing rules, and the other is to re-build rule base from ground zero.

Most fuzzy control rules are described by "if ... then ⋯". However, based on the difference in premise and conclusion sections, there are three commonly-used forms:

1. Standard Form:

If X is Al and Y is Bl, then Z is Cl;

If X is A2 and Y is B2, then Z is C2;

:

:

If X is An and Y is Bn, then Z is Cn.

This form is the most commonly-used fuzzy rule, primarily applied to the systems of multiple inputs and single output (MISO). [Note: X and Y are input variables, Z is output variable; An is the nth rule, semantic variable of input variable in premise; Bn is the nth rule, semantic variable of output variable in conclusion.]

2. Function Output Form: If X is Al and Y is Bl, then Z is F(X, Y).

   This form is the rule proposed by Professor Sugeno, where the output is the linear or non-linear function of input.

3. Special Form: If (U is C1 → X is A1 and Y is B1), then U is C1.

   This control rule can be interpreted as: "If assessment index X is A1 and assessment index Y is B1 when U takes action C1, then control command U can perform action C1". This form intends to increase the predictability of fuzzy control. As long as the output approximates certain output, this rule can be activated. However, the behavior of systems is not easy to forecast since it varies drastically.

2.4 Fuzzy Inference

Fuzzy inference is the new conclusion drawn from the rules in rule base and the facts given. Fuzzy inference is developed from the concept of analogy and includes forward and backward chaining. Since forward chaining is the computation process of deriving results after information is acquired, it is applicable to fuzzy control. The format is as follows:

Rule: If X is A, then Y is B; Fact: X is A'; Conclusion: Y is B'.

Fuzzy inference is a rather important topic in the research scope of fuzzy theory. Many scholars have proposed different methods, which can be roughly divided into direct and indirect inference. Direct inference is adopted in this study. The process is illustrated in Figure 3 below:

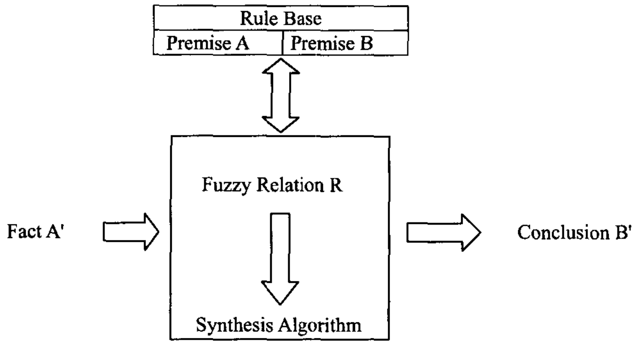

Figure 3. Structure of Fuzzy Inference

"X is A" in "if" part is premise; and "Y is B" in "then" part is conclusion, where both A and B are fuzzy sets. In direct inference, these relations are denoted by the fuzzy relation R. Conclusion B' is inferred through synthesis algorithm of R and A'. In this study, "max-min" inference is adopted for synthesis algorithm of fuzzy relations. By "max-min" inference, the applicability of the rule or the "actual value" is connected by the premise part of the rule to become the minimum rule for measurement as well as the premise part of the minimum rule for decision-making. The "actual value" is applied to all the results of the rule. If there is more than 1 fuzzy output, then select the maximum output.

2.5 Defuzzification

The primary goal of defuzzification is to convert the average value of inference results to the actual value. In other words, the job of defuzzification is to convert output from fuzzy set to common set. There are many methods of defuzzification. The followings are the most commonly-used ones: (1) center of gravity; (2) weighted average; (3) high method; and (4) area method. This study uses weighted average to define the degree of membership as weight coefficient and consider the contribution of all elements, which can satisfy the requirements of this study. The formula is as follows:

$$Z = \frac{\sum_{i=1}^{n} WiXi}{\sum_{i=1}^{n} Wi} \qquad (5)$$

W_i: the actual degree of the ith membership function.

n: number of quantified conclusions.

X_i: the assumed value when the *i*th membership function reaches the maximum value (taking triangular membership function for example, this is its vertex.).

3. Case Study

The department of light production of an electronics company is used as an example in case study. Its major products are: fluorescent straight tube (FL-20W, Fl-40W), energy-saving tube 17W (electronic and traditional), bulb (110V-25W ~ 110V-250W; 220V-25W ~ 220V-250W), 3U tube (FTL: 18W, 26W, 2W, 42W; EFG: 20W, 23W; EF: 18W, 2lW, 24W). Its monthly output is: 3.5 million fluorescent straight tubes, 150 thousand fluorescent circular tubes, 1.2 million bulbs, 300 thousand bulbs for cars, 200 thousand energy-saving bulbs, and 150 thousand 3U tubes. Its manufacturing process is shown in Figure 4 below.

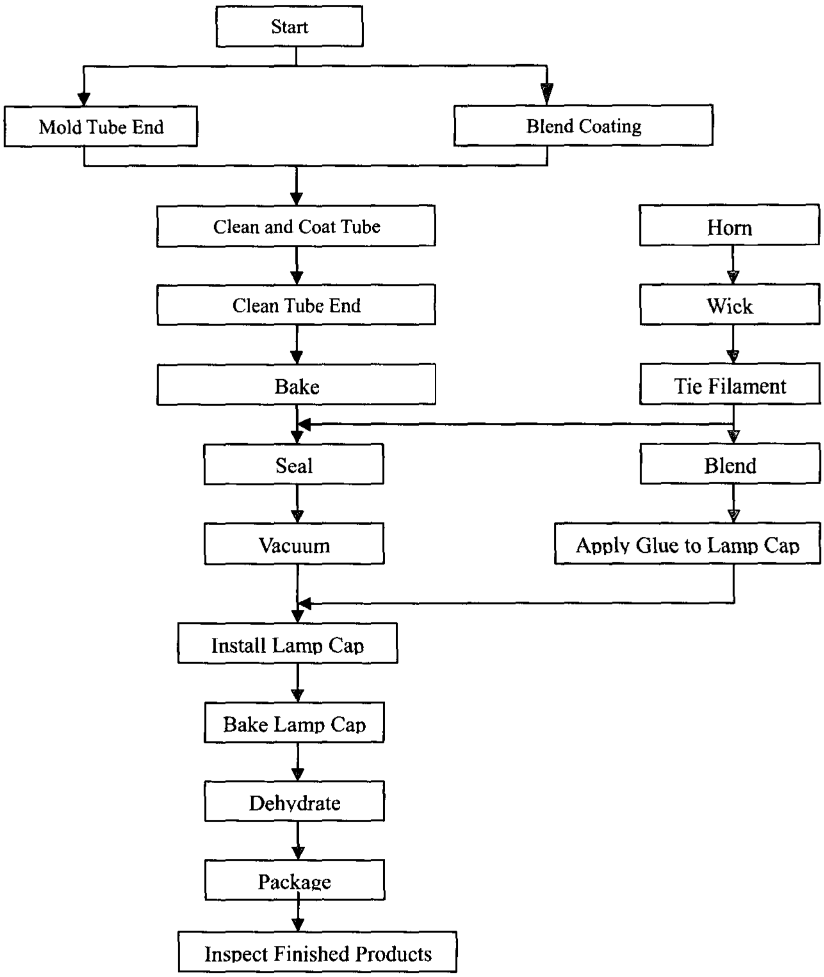

Figure 4. Manufacturing Process of Fluorescent Lamp

The inputs and outputs of various operating units involved in this manufacturing process are listed in Table 7.

Table 7. List of Waste Disposal from Department of Fluorescent Lamps Production

Unit name	Input	Output
Molding Tube End	Glass tube, coolant, gas, electricity, SO2, hydrogen	Waste glass, defective products, waste engine oil, hot air
Blending Coating	Dispersing agent, purified water, LAQ dissolvent, phosphor powder, chemical compound, vinegar acid	Chemical dissolvent, phosphor powder, chemical compound, empty barrel, waster water
Cleaning and Coating Tube	Water, gas, electricity	Defective tube, phosphor deposit, waste water of coating, hot air
Cleaning Tube End	Gas, nylon brush, powder	Waste nylon brush, phosphor powder agent, defective product
Baking	Gas, electricity	Defective product, hot wind
Sealing	Gas, electricity, tube, wick, high-pressure air	Defective product, hot air
Vacuuming	Water, gas, electricity, mercury, hydrogen, ammonia, high- and low-pressure gas	Defective tube, stray air
Installing Lamp Cap	None	Waste conducting wire
Baking Lamp Cap	Gas, air	Defective tube, hot air
Dehydrating	Electricity	Defective tube
Packaging	Inner package, outer box	Defective tube
Inspecting Finished Products	Electricity	Defective tube
Horn	Horn tube, coolant, gas, electricity, high-pressure air, SO2	Waste glass, waste water, hot wind
Wick	Horn, conducting wire, vacuuming tube, electricity, high-pressure air, vacuuming tube, So2, hydrogen	Defective glass
Tying Filament	Wick, cathode, filament, gas, electricity, high- and low-pressure air, cathode blending dissolvent	Defective glass, empty barrel for dissolvent, defective filament
Blending	Lime powder, denatured alcohol	Empty bag, empty barrel for alcohol
Applying Glue to Lamp Cap	Glue for lamp cap	Defective tube

The prevailing method that is used by average manufacturers to assess environmental impact is significant factor approach, which gives scores to the decision factors such as frequency, probability, and gravity etc. of environmental aspects according to the preset scoring standard of the organization, sums up to get the total scores for environmental aspects, and ranks them by score. In this study, six experts were interviewed, so geometric average is employed to arrive at average significance, which is then used as the basis for risk ranking. The risk assessment and ranking of solid wastes from Department of Fluorescent Lamps are shown in Table 8. The risk assessment and ranking of liquid and gas wastes from Department of Fluorescent Lamps are shown in Table 9. The risk assessment and ranking of solid wastes from Department of Special Control are shown in Table 10. The risk assessment and ranking of liquid and gas wastes from Department of Special Control are shown in Table 11.

The analysis by comparing the traditional significant factor method and the method used in this study in risk assessment and ranking of solid, liquid, and gas wastes shows significant variance in the results of average significance and risk ranking in various aspects of solid, liquid, and gas wastes from both Department of Fluorescent Lamps and Department of Special Control. The ranking results are illustrated as follows:

1. Glass tubes are heated by tube end molding machine and cut into the sizes required. The raw material of the waste glass cut off is silicon sand with high dissolvability. The waste glass produced in this phase does not contain any toxic material or other ingredients and thus can be re-classified and reused after recycled. Since the waste glass produced per month reaches about 3,000 kilograms, which is considered a fairly large quantity, assessing environmental impact by traditional method is highly risky. However, the impact of waste glass output is relatively low and the impact of dissolvability is relatively high, hence, in the new method, as a smaller weight is given to output and a greater weight is given to dissolvability, the risk involved is reduced substantially. This is because that the traditional method does not consider the different degrees of impact that various decision factors have on environment. Consequently, the results derived from the new method are superior to those from the old method.
2. With regard to the nylon brushes discarded by tube end cleaning machine, the raw material is plastic, which can hardly be dissolved naturally, that is, dissolvability is low; and thus must be recycled and smashed before reused, that is, recyclability is low. About 8 ~ 10 kilograms of nylon brushes are discarded each month, so the quantity is extremely small. By comparison, the risk ranking by the new method improves

Table 8. Comparison of New and Old Methods in Risk Assessment and Ranking of Solid Wastes from Department of Fluorescent Lamps

Code	Explanation	Traditional Score	Ranking	Score by This Model	Ranking
1	Waste glass from heating glass tube by tube end molding machine	19.33	9	2.89	18
2	Defective products from cutting tube by tube end molding machine	18.33	11	2.88	21
3	Empty barrels for acid or alkali materials used in blending coating	19	10	3.75	3
4	Defective products from cleaning and coating tube, and coating materials from cleaning waste defective tube by water	12.67	16	2.52	23
5	Phosphor agent sediment produced by putting the waste water from cleaning and coating tube in precipitating tank	11	21	3	14
6	Nylon brushes scrapped by tube end cleaning machine	12.33	17	3.78	2
7	Phosphor powder attached to machinery and floor after cleaning tube end	6.67	23	2.33	24
8	Defective or scrapped parts from cleaning tube end	11.33	18	3	14
9	Defective products from baking fluorescent lamp: waste tubes	11.33	18	3	14
10	Waste glass left after cutting horn tube by the cutter of horn machine	20.33	7	2.89	18
11	Defective products from wick machine: waste glass	20.33	7	2.89	18
12	Defective products from tying filament: glass tube	16.83	11	2.88	21
13	Empty barrels for cathode blending dissolvent used in tying filament	14.5	15	4	1
14	Defective filament resulted from the process of tying filament	6.17	24	3	14
15	Defective products from the fluorescent tube sealing process	30.67	5	3.29	12
16	Empty bags used by glue for lamp cap	10.67	22	3.47	5
17	Empty barrels for denatured alcohol used in blending the glue for lamp cap	15.5	14	3.57	4
18	Defective products from applying glue to lamp cap: waste tubes	46.67	3	3.29	12
19	Defective products from vacuuming process: waste tubes	4.83	4	3.31	6
20	Waste conducting wire from installing lamp cap on fluorescent lamp	11.17	20	3.3	11
21	Waste fluorescent tubes from lamp cap baking process of fluorescent lamps	20.5	6	3.31	6
22	Waste fluorescent tubes from dehydrating process of fluorescent lamps	47.5	1	3.31	6
23	Waste fluorescent tubes from packaging process of fluorescent lamps	16.83	11	3.31	6
24	Defective products from finished product inspection process of fluorescent lamps	47.5	1	3.31	6

significantly because the disadvantage of this aspect is low dissolvability, which has greater impact on environment regardless of the advantages in high recyclability and low output. As the traditional method does not take into consideration the variance in degree of impact that different decision factors have on environment, the results obtained from the new method are superior to those from the old method.

Table 9. Comparison of New and Old Methods in Risk Assessment and Ranking of Liquid and Gas Wastes from Department of Fluorescent Lamps

Code	Explanation	Traditional Score	Ranking	Score by This Model	Ranking
1	Waste engine oil disposed from maintaining tube end molding machine	24.5	7	4.62	2
2	Hot air constantly disposed from cutting tubes by tube end molding machine	61.67	2	4.33	3
3	Waste water disposed from blending coating	48.17	4	4.22	5
4	Sediment produced by putting the waste water from cleaning and coating tubes in precipitating tank	41.67	5	3.76	7
5	Hot airfrom dehydrating by oven in cleaning and coating tube	14.83	8	2.59	8
6	Waste water disposed into drain by cleaning the defective products from coating by water	35.33	6	3.8	6
7	Hot air from baking lamp cap of fluorescent lamp disposed outside of the factory	14.17	9	2.59	8
8	Hot air from heating when cutting horn tube by horn machine disposed outside of the factory	58.17	3	4.33	3
9	Hot air from heating when soldering tube and wick glass disposed outside of the factory	14.17	9	2.59	8
10	Waste air disposed outside of the factory by vacuum	79.17	1	4.64	1
11	Hot air from heating when baking lamp cap disposed outside of the factory by air pump	14.17	9	2.59	8

Table 10. Comparison of New and Old Methods in Risk Assessment and Ranking of Solid Wastes from Department of Special Control

Code	Explanation	Traditional Score	Ranking	Score by This Model	Ranking
1	Waste glass and defective products from cutting glass tubes by cutting machine	17	7	2.89	13
2	Defective glass tubes from molding by bending machine and soldering machine	17	7	2.89	13
3	Empty barrels for acid or alkali materials used in blending coating	16.67	9	3.47	6
4	Phosphor agent deposit from washing coating materials of the defective products produced by tube cleaning and coating machine	11	15	3	12
5	Defective sediment from cleaning coating recycling notch of tube cleaning and coating machine	35	4	4	1
6	Nylon brushes scrapped by tube end cleaning machine	12.33	14	3.78	3
7	Phosphor powder left on machinery and floor in cleaning tube end	4.5	20	2.33	19
8	Defective scrapped parts from cleaning tube end	14	12	3.14	10
9	Defective products from baking fluorescent lamps: waste tubes	14	12	3.14	10
10	Waste glass and defective products from cutting horn tube by horn machine	7.5	17	2.34	16
11	Defective products produced by wick machine: waste glass	7.5	17	2.34	16
12	Defective products produced by filament tying machine: waste glass	7.5	17	2.34	16
13	Empty barrels from cathode blending dissolvent used in tying filament	14.5	11	4	1
14	Defective products from sealing tubes by sealing machine	18.67	6	2.81	15
15	Defective products from soldering tubes by soldering machine: waste vacuum tubes	37	3	3.72	4
16	Defective products from vacuuming tubes by vacuum: waste vacuum tubes	50	1	3.31	8
17	Defective products from dehydrating tubes: waste tubes	28.5	5	3.45	7
18	Disposed packages or holders of various materials used in assembling energy-saving bulbs and 3U tubes	10.67	16	2.29	20
19	Empty barrels or bags for raw materials used in blending by gluing machine A and B	15.33	10	3.67	5
20	Defective products from inspection process of finished products of energy-saving bulbs and 3U tubes	50	1	3.31	8

Table 11. Comparison of New and Old Methods in Risk Assessment and Ranking of Liquid and Gas Wastes from Department of Special Control

Code	Explanation	Traditional Score	Ranking	Score by This Model	Ranking
1	Waste water from cleaning mixer in blending coating	48.17	2	4.25	3
2	Waste water disposed from cleaning and coating glass tubes	41.67	3	2.76	5
3	Hot air from heating by oven in cleaning and coating tubes disposed outside of the factory by air pump	15.83	6	2.59	6
4	Waste water from cleaning the defective products produced by tube cleaning and coating machine disposed into drain after precipitated in precipitating tank	38.17	4	3.78	4
5	Hot air from baking tubes disposed outside of the factory by air pump	15.83	6	2.59	6
6	Mixed air pumped by vacuum disposed outside of the factory	85	1	4.63	2
7	Waste engine oil disposed in maintaining vacuum	35.5	5	4.64	1
8	Hot air from heating in applying glue to tubes disposed outside of the factory by air pump	15.83	6	2.59	6

3. In terms of the waste tubes from baking fluorescent lamps, the raw material is silicon sand, which is highly dissolvable. However, the waste tubes produced in this phase contain the coating material of phosphor agent, the waste glass cannot be recycled, that is recyclability is low. The monthly output is 60 kilograms, i.e. extremely low output. Therefore, this aspect is characterized by high dissolvability, low recyclability, and extremely low output. Based on the comparison of the new method and the old method, the risk ranking resulted from the new method has increased slightly. The disadvantage of this aspect is low recyclability. However, recyclability has relatively low impact on environment. Consequently, with a small weight given to recyclability in the new method, the risk ranking has improved but not significantly. Compared to the traditional method, the new method takes into account the variance in impact that different decision factors have on environment, and thus produces results superior to those produced by the traditional method.

4. Conclusions

Based on the comparison of risk ranking and environmental impact of decision factors, the ranking derived from the new method can better represent the degree of impact that environmental aspects have on environment. During the complete experiment process, a total of 63 environmental aspects of waste disposal produced by the manufacturing process are included in the risk ranking by the traditional method and the new method proposed by this study. The comparison shows 9 same rankings, 24 decreased rankings, and 30 increased rankings. The reason for the variance of these 63 aspects is that the traditional method considers the quantified sum of decision factors only and ignores the variance in the degree of impact that environmental aspects in terms of decision factors have on environment. The model proposed in this study gives different weights to different degrees of environmental impact that environmental aspects have in terms of each decision factor, and hence can better represent the degree of environmental impact that environmental aspects have. In the above case study, the new method has changed the riskiest environmental aspect that requires first priority for improvement. The resulting ranking is also different. Since the traditional significant factor method does not take into account the variance in the degree of impact that different decision factors have on environment whereas the new method solves the problem associated with the traditional method that decision factors cannot have relative weights, the new method can better represent the gravity of the risk in all environmental aspects.

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