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Material Flow Analysis for Industrial Waste Management in Thailand

by

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Abstract

Material flow analysis (MFA) is an excellent tool in supporting decision making regarding waste management problems. MFA allows the calculation of the amount and composition of wastes by balancing the process of waste generation and the process of waste treatment. MFA can be used to analyze wastes flow because inputs-outputs of waste treatment can be linked.

The industrial waste management system in Thailand is still lacking comprehensive data on industrial waste generation and flow. Therefore, MFA can be used to determine inputs-outputs of the waste treatment processes.

This study estimated the annual amount of the total industrial waste generation in Thailand from 1999 through 2004. It calculated industrial waste flows and employed MFA to illustrate the flows of industrial waste from waste generators to waste disposers. Using the industrial waste flow was effective in analyzing the waste management system in Thailand. The industrial waste flows show the dominant waste treatment method of Thailand was reuse and recycling, accounting for 83.6 % of disposal on the average from 2002 to 2004.

Industrial waste generation, y in millions of tons, had an interrelation with economic growth (gross domestic product per capita) of the country, x in US$ as $y = -1.0059 + 0.0054x$. The correlation coefficient was 0.7616 which can be assumed to represent a good relationship. The average waste generation per GDP and waste generation per capita in Thailand from 1999 to 2004 were 80.3 kg per 1,000 US$ and 215 kg per person respectively.

Keywords: Industrial waste management, Industrial waste flow analysis, Waste data collection system, Material flow analysis, Industrial waste estimation

1. Introduction

Determining the amount and types of waste generated within a region is of fundamental significance for waste management planning and control[1), 2), 3)]. Data gathered with regard to amount, waste type and origin are important when designing a waste data collection system[4), 5), 6)]. A waste management system cannot be successful without complete and timely waste data that

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reflect the current waste situation[7),8),9),10)].

Since 2001, Thailand has gathered relatively accurate data on industrial wastes originating from the registered factories all over the country. Thailand's regulations require the more than 122,050 registered factories, to declare the amount of their generated industrial wastes by waste type as well as their recycling and disposal waste treatment plans to the Ministry of Industry (MOI) every year. So far there have been more than 33,833 waste treatment and disposal plans submitted to the MOI. The number of registered factories for each size category and the number of waste Treatment and disposal plans submitted to the MOI are shown in **Table 1**.

Table 1 Number of registered factories for each size category and number of waste treatment and disposal plans.

Scale of Factory	Number of Registered Factories	Number of Registered Factories that submitted waste treatment/disposal plan	% Number of Registered Factories that submitted waste treatment/disposal plan	Number of Submitted waste treatment/disposal plan
Group 1 Power of machines ≤ 20 H.P. and Employee ≤ 20 persons	54,184	613	1.1313%	2,261
Group 2 Power of machines ≤ 50 H.P. and Employee ≤ 50 persons	29,438	1,980	6.7260%	6,034
Group 3 Power of machines > 50 H.F and Employee > 50 persons	38,428	5,367	13.9664%	23,192
Sub Total	122,050	7,960	6.5219%	31,487
Unidentified Factory		697	0.5711%	2,346
Total		8,657	7.0930%	33,833

IDE-JETRO[11)] studied industrial waste generation in Thailand and estimated amounts from 1999 to 2004 as shown in **Fig.1**. It was found the amount of industrial waste generation in Thailand fluctuated around 12.8 millions of tons per year from 1999 to 2002. There was then an abrupt increase of 25% or 3.2 millions of tons from 12.8 millions of tons in 2002 to 16 millions of tons in 2004. This abrupt change in the industrial waste amount is so significant that the main causes need to be investigated. However, no study has been carried out to explain the phenomenon. This may be because of a lack of an effective analysis tool. This is one reason why a systematic and efficient tool that can monitor and analyze an industrial waste system should be designed and developed as soon as possible.

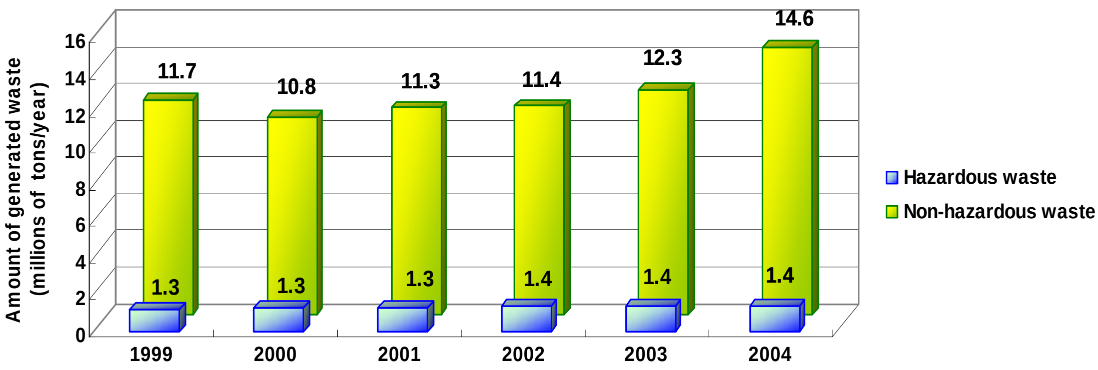

Fig.1 Amount of industrial waste generation.

2. Background and Situation of Industrial Wastes Generation in Thailand

2.1 Industrial wastes

2.1.1 Terminology

According to the report of Industrial Waste Management and Recycling in Thailand conducted in 2006 by the Institute of Developing Economies Japan External Trade Organization (IDE-JETRO) and Energy, Industry and Environment Thailand Environment Institute, an official definition of industrial waste in general has not been addressed in any legislation. There are various definitions stated in relevant laws and regulations that are related to industrial waste recycling and management. Thus, industrial waste terminology seems to be subjective to the context of application, as found in the following.

2.1.1.1 Industrial wastes

Industrial waste can be classified into two major categories as follows (Application guidelines for offsite industrial waste transportation approval).[12]

1) Non-hazardous waste refers to wastes generated in manufacturing or production that are not harmful to humans, property or the environment.

2) Hazardous waste refers to solid, liquid or gaseous wastes, that are harmful, such as highly flammable, corrosive, highly reactive or toxic substances, which also include treated hazardous waste. These definitions are according to the findings of "The Study on the Master Plan on Industrial Waste Management in the Bangkok Metropolitan Area and its Vicinity in the Kingdom of Thailand" conducted in 2001 by the Japan International Cooperation Agency (JICA)[13] and the Department of Industrial Works (DIW).

2.1.1.2 Waste generator

Waste generator refers to a factory that generates or possesses industrial waste listed in the waste and unused material inventory attached to the Ministry of Industry's 2005 Decree on the Disposal of Wastes and Unused Materials, including hazardous substances indicated in the 1992 Hazardous Substance Act. To fall under the waste generator category, a factory has to generate at least 100 kilograms of hazardous substances per month. Factories are divided into two categories:

1. Large industrial waste generators generate more than 1,000 kilograms of industrial waste per month.
2. Medium industrial waste generators generate more than 100 kilograms but less than 1,000 kilograms of industrial waste per month.

2.1.1.3 Waste treatment / disposal method

Waste treatment refers to the collection, storage, treatment and disposal of industrial waste in a central waste treatment plant or landfill disposal, burning or other means of treating or disposal of industrial waste. Waste treatment is usually conducted in factories that produce raw materials or new materials with unused industrial products or wastes using certain industrial production processes. These factories usually include industrial codes 101, 105 and 106 based on the 1992 Factory Act, industrial waste transporting station, industrial waste storing facilities and factories that collect and dispose or treat radio active waste.

Waste treatments are classified into three types:

1. Industrial code 101 factories treat wastewater and dispose industrial waste using industrial waste furnaces or a high temperature incinerator, or stabilize industrial waste.
2. Industrial code 105 factories bury landfill or separate industrial waste.
3. Industrial code 106 factories recycle industrial waste.

2.2 Laws and provisions on industrial wastes

Currently there is only one active law on the management and recycling of industrial wastes. This law, as part of the Hazardous Substance Act 1992, is named the Notification of the Ministry of Industry's 2005 on the Documentation System on the Transportation of Hazardous Wastes. This law relates to the controlling and monitoring of hazardous wastes from waste generators to waste treatment by hazardous waste transporters. It also includes the controlling and monitoring of hazardous waste storage by waste generators. The Notification of the Ministry of Industry's 2005 is summarized as follows.

1) Hazardous wastes of 1,000 kilograms or more can be stored in factories no longer than 90 days from the day the wastes were generated. Hazardous wastes of 100 kilograms or more, but less than 1,000 kilograms can be stored in factories no longer than 180 days from the day the wastes were generated.

2) This Notification of the Ministry of Industry applies to factories generating h 100 kilograms or more per month of hazardous waste. Hazardous waste generators that generate less than 100 kilograms per month are exempted from this notification, although they are required to abide by the Notification of Ministry of Industry's 2005 "management of waste or unused materials".

3) Hazardous waste generators and hazardous waste treatment facilities must prepare an annual report at least once a year (by the 1st of March) to inform the Department of Industrial Works of the hazardous waste processing. The report must include information on the amount of hazardous waste and hazardous waste processing management plan.

3. Classification Systems

3.1 Classification of industrial sector

The industrial waste data collected by the MOI are classified using 107 types of industry, 808 types of waste and 18 types of waste treatment facility.

Each factory in Thailand, when registering with the MOI, must declare itself to be in only one of the 107 types of industry. A registered factory is also classified by its size as small, medium or large. The size of the factory is determined by the number of workers in the factory as well as the total horsepower of machines used by the factory. This study compiled these 107 types of industry and categorized them into 17 industrial sectors based on Thailand standard industrial classification (TSIC) as shown in **Table 2**.

Table 2 Industrial sectors.

Sector no.	Industrial sector name
001	Agriculture, Hunting and Forestry
002	Mining and Quarrying, Electricity, Gas and Water Supply
003	Food Products, Beverage and Tobacco
004	Textiles, Luggage and Footwear
005	Woods, Products of Wood and Furniture
006	Coke, Refined Petroleum Products
007	Rubber, Plastics and Non-Metal Products
008	Basic Metal, Machinery and Equipment
009	Other Machinery, Radio, Television
010	Medical, Precision and Optical Instruments
011	Motor Vehicles, Trailers, Transport Equipment
012	Other Manufacturing and Recycling
013	Construction
014	Wholesale and Retail Trade, Repair of Motor Vehicles
015	Transport, Storage and Communication
016	Financial Intermediation, Real Estate, Renting
017	Other Community, Social and Personnel Service Activities and Other Services

Table 3 Waste types.

Industrial waste type	Waste name
Non-hazardous waste	Food waste
	Wood waste
	Paper waste
	Plastic waste
	Rubber waste
	Metal waste
	Glass waste
	Construction waste
	Other Non-hazardous waste
Hazardous waste ; Spent solvents, waste water treatment sludges, etc.	

3.2 Classification of waste type

The MOI classifies industrial wastes or discarded materials into 808 types. Every factory wishing to bring its generated waste or discarded materials out of the factory must declare the amount and types of waste. A declared waste type must be one of these 808 waste types. In this study, the 808 waste types were categorized into 10 groups as shown in **Table 3**.

3.3 Classification of waste treatment

In disposing generated waste, a factory must submit an application for a waste permit to the MOI and identify the waste treatment facilities that will be used in disposing the generated wastes. The declared waste treatment facilities must belong to the 18 types of waste treatment facility as defined by the MOI. In this study, the 18 types of waste treatment facility were categorized into four groups as shown in **Table 4**.

Table 4 Waste treatment methods.

Waste treatment method	Detailed method
Intermediate treatment	Sorting
	Incineration
	Chemical and physical treatment
Reuse and recycling	Use as raw materials
	Composting
	Animal feed
	Fuel blending
	Incineration in cement kiln
	Other reuse and recycling
Final disposal	

4. Data Gathering Methods

4.1 Data sources

Industrial waste data were collected and prepared by different organizations. The MOI is authorized to control all factories in Thailand. The waste database of the MOI, which is the most complete and up to date, was used in this study for data retrieval, data conversion, data calculation and data analysis.

4.1.1 Economic statistics

In Thailand, the National Economic and Social Development Board (NESDB) is responsible for collecting and preparing the economic data of the country. However, to obtain all the relevant data needed by this study requires a great deal of time and effort.

4.1.2 Interrelation between the economy and industrial waste generation

Using the industrial waste data from the industrial waste data collection system of Thailand, the industrial waste generated from 1999 to 2004 was extracted. Calculations of the total waste generation were carried out. With the relevant economic data in a corresponding year as shown in **Table 5**, the waste generation per gross domestic product (GDP) and waste generation per capita were computed and are shown in **Fig. 2**.

The economic data from 1999 to 2004 needed in the calculations were collected and are shown in **Table 5**. These economic data are population and its growth rates, GDP, GDP per capita, and amount of industrial waste generated.

Table 5 Population, GDP and waste generation in Thailand.

Population	Year					
	1999	2000	2001	2002	2003	2004
Total population (millions)	61.66	61.88	62.31	62.80	63.08	61.97
Population growth rate (%)	0.32	0.35	0.7	0.79	0.45	-1.75
GDP (billions US$) in constant 2000 prices	148.84	155.91	159.29	167.93	178.92	187.67
GDP per capita (US$)	2,414	2,520	2,556	2,674	2,836	3,028
Total waste generation (millions of tons)	12.95	12.09	12.61	12.80	13.70	16.00
Waste generation per GDP (kg per 1,000 US$)	87.01	77.55	79.16	76.23	76.57	85.28
Total waste generation per capita (kg per person)	210.02	195.38	202.38	203.83	217.19	258.25

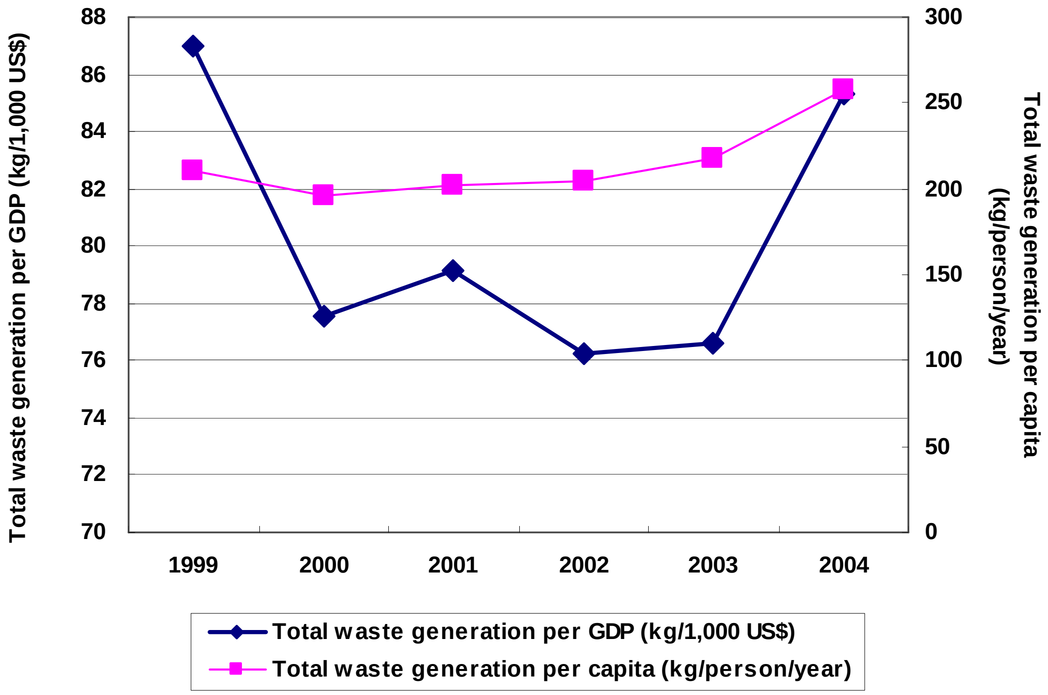

Fig. 2 Total Industrial waste generation per capita and per GDP.

4.1.3 Regression function between wastes generation and economic growth

To find the relationship between the industrial waste generation and the economic situation of Thailand, the total annual waste generation from 1999 to 2004, y (in millions of tons), was plotted against the GDP per capita in the corresponding year, x (in US$), as shown in **Fig. 3**. The linear regression line between these two variables was calculated as

$$y = -1.0059+0.0054x$$

with the correlation coefficient $R^2 = 0.7616$.

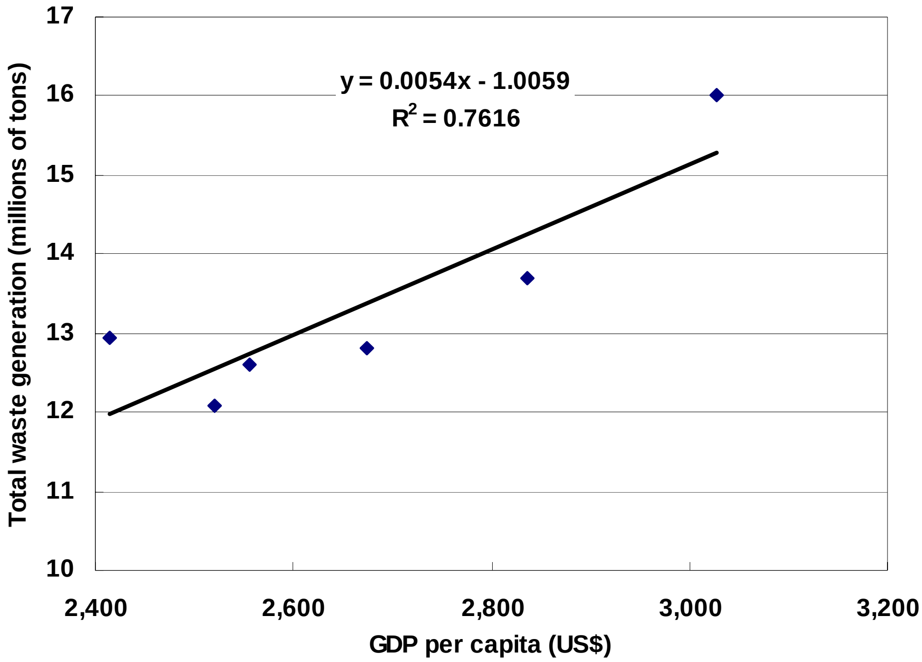

Fig. 3 Relationship between total annual waste generation and GDP per capita for Thailand.

4.1.4 Interrelation between waste generation rate per worker and production output

Plubcharoensuk[14)] studied the industrial waste flow in Thailand using the structural decomposition analysis method. The production outputs of 17 industrial sectors in 2002 and 2004 were obtained in this study and are shown in **Tables 6** and **7** respectively. The numbers of workers in each industrial sector and year were obtained from the Department of Labor and are shown in **Tables 6** and **7**. From these data, the waste generation rate per worker (in kg per person) and the GDP per worker (in baht per person) were calculated and are shown in the corresponding table.

Table 6 Waste generation and production output in the fiscal year of 2002.

Sector no.	Industrial sector name	Total waste in 1,000 tons	Number of labors in 1,000 person	Waste generation per labor (kg/person)	Production output in millions baht	GDP per labor (baht/person)
001	Agriculture, Hunting and Forestry	36	14,042	3	889.24	63.33
002	Mining and Quarrying, Electricity, Gas and Water Supply	3,368	133	25264	529.28	3,969.66
003	Food Products, Beverage and Tobacco	2,748	705	3900	1,300.37	1,845.06
004	Textiles, Luggage and Footwear	164	596	276	981.81	1,646.90
005	Woods, Products of Wood and Furniture	1,334	132	10078	281.14	2,123.95
006	Coke, Refined Petroleum Products	246	145	1689	1,098.58	7,552.63
007	Rubber, Plastics and Non-Metal Products	1,600	505	3171	487.44	966.05
008	Basic Metal, Machinery and Equipment	1,436	479	2996	365.85	763.30
009	Other Machinery, Radio, Television	472	1,671	282	717.08	429.07
010	Medical, Precision and Optical Instruments	148	246	600	862.29	3,505.46
011	Motor Vehicles, Trailers, Transport Equipment	408	453	899	491.10	1,082.92
012	Other Manufacturing & Recycling	164	119	1379	124.92	1,049.83
013	Construction	0	1,787	0	421.76	236.07
014	Wholesale and Retail Trade, Repair of Motor Vehicles	0	4,946	0	1,545.55	312.51
015	Transport, Storage and Communication	0	1,009	0	912.63	904.64
016	Financial Intermediation, Real Estate, Renting	0	773	0	807.38	1,045.11
017	Other Community, Social and Personnel Service Activities and Other Services	677	5,305	128	541.58	102.10
	Total	12,801	33,046	387	12,358.00	373.97

5. Analysis of Industrial Waste Flows

5.1 Model formulation

Industrial sectors or factories always generate waste of some sort while producing useful products supplying the nation economy. There are thousands of factories in Thailand in operation and generating industrial waste everyday. To determine the amounts and types of waste generated by these factories, a matrix-type model, which is a basic and systematic tool, was designed and developed. The model consisted of three parameters: type of industry, type of waste generated and type of waste treatment facility. The three parameters can represent the industrial waste system of the country as a cube. Thus the developed model is referred to as a waste cube model in this study.

Table 7 Waste generation and production output in the fiscal year of 2004.

Sector no.	Industrial sector name	Total waste in 1,000 tons	Number of labors in 1,000 person	Waste generation per labor (kg/person)	Production output in millions baht	GDP per labor (baht/person)
001	Agriculture, Hunting and Forestry	349	13,634	26	1,182.03	86.70
002	Mining and Quarrying, Electricity, Gas and Water Supply	1,482	151	9830	709.19	4,703.79
003	Food Products, Beverage and Tobacco	2,827	636	4444	1,643.11	2,583.08
004	Textiles, Luggage and Footwear	1,063	884	1202	1,169.98	1,323.26
005	Woods, Products of Wood and Furniture	1,487	251	5915	367.43	1,462.03
006	Coke, Refined Petroleum Products	914	179	5115	1,487.44	8,323.93
007	Rubber, Plastics and Non-Metal Products	1,494	660	2262	603.96	914.61
008	Basic Metal, Machinery and Equipment	4,038	615	6570	327.96	533.62
009	Other Machinery, Radio, Television	613	1,231	498	858.25	697.48
010	Medical, Precision and Optical Instruments	138	225	614	940.10	4,184.19
011	Motor Vehicles, Trailers, Transport Equipment	893	544	1642	585.45	1,076.55
012	Other Manufacturing & Recycling	361	252	1432	175.64	697.18
013	Construction	3	2,080	2	569.75	273.87
014	Wholesale and Retail Trade, Repair of Motor Vehicles	0	5,540	0	1,932.71	348.85
015	Transport, Storage and Communication	0	1,100	0	1,186.02	1,077.77
016	Financial Intermediation, Real Estate, Renting	0	920	0	1,015.83	1,103.59
017	Other Community, Social and Personnel Service Activities and Other Services	344	5,796	59	698.65	120.54
	Total	16,005	34,698	461	15,453.51	445.37

5.1.1 Waste-cube model for industrial waste data

The model extracted industrial waste data from the waste data collection system of Thailand and presented the data in 3-dimension form as a waste cube. These three dimensions were the industrial sector, type of waste generated and type of waste treatment facility used in the waste disposal. The related economic parameters, population statistics and production output were also used in the model.

With these data, the waste generation per worker and waste generation per GDP per capita could be calculated and used in analyzing the waste management system efficiency.

The details of the model are as follows.

Let u_{ij} = amount of waste in tons of waste type j generated by industrial sector i,

w_{ijk} = amount of waste in tons of waste type j generated by industrial sector i and disposed using waste treatment k, as has been requested to be brought out of the factory

$$\text{Then} \qquad u_{ij} = \sum_{k=1}^{K} w_{ijk}$$

5.1.2 Industrial waste flow model

The industrial waste management system of Thailand can be analyzed systematically using the waste cube model. Industrial waste flows can be calculated and illustrated.

Let there be five nodes in the industrial waste flow system as shown in **Table 8**.

Table 8 Nodes in the industrial waste flow system.

Node number	Node name
1	Waste generator
2	Intermediate treatment
3	Reuse and recycling
4	Final disposal
5	Export

The industrial waste flow system is shown in **Fig. 4** as a network model.

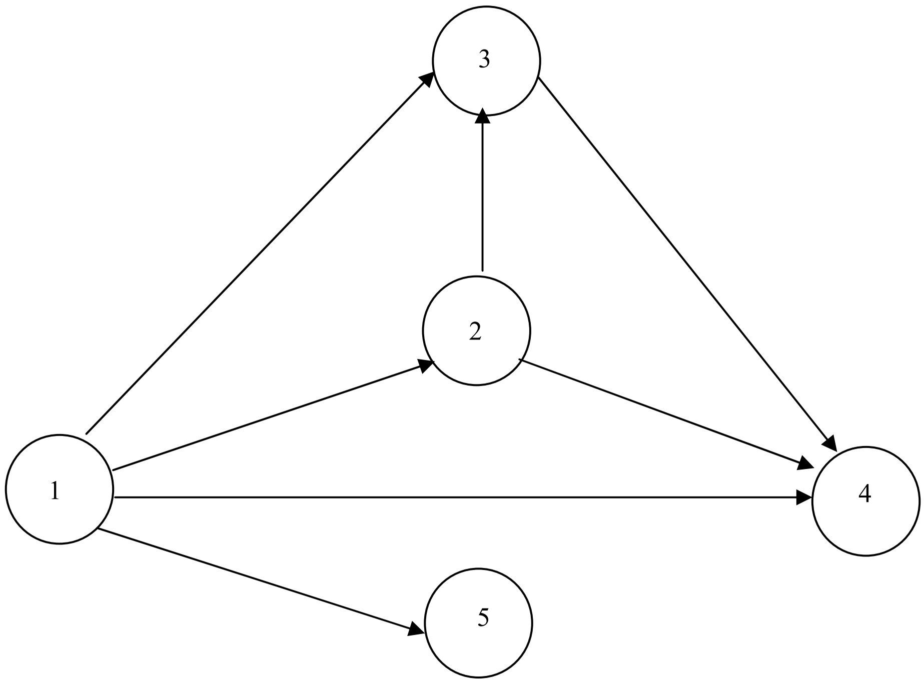

Fig. 4 Network model of the industrial waste flow system.

Let x_{mn} = Amount of waste flow from node m to node n,
where m, n = 1, 2, …, 5

The situation at each node is as follows.

Node 1: Amount of waste generated by the waste generator = $x_{12} + x_{13} + x_{14} + x_{15}$

Node 2: Amount of waste disposed by the intermediate treatment = x_{12}

Node 3: Amount of waste disposed by reuse and recycling treatment = $x_{13} + x_{23}$

Node 4: Amount of waste disposed by final disposal treatment = $x_{14} + x_{24} + x_{34}$

Node 5: Amount of waste disposed by export treatment = x_{15}

Using the waste cube model, x_{mn} can be calculated as follows.

$$x_{12} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ waste generators

and k ∈ intermediate treatments;

$$x_{13} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ waste generators

and k ∈ recycle and reuse treatments;

$$x_{14} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ waste generators

and k ∈ final disposal treatments;

$$x_{15} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ waste generators

and k ∈ export treatments;

$$x_{23} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ intermediate treatments

and k ∈ recycle and reuse treatments;

$$x_{24} = \sum_{j=1}^{J} w_{ijk}$$ where i ∈ intermediate treatments

and k ∈ final disposal treatments;

$$x_{34} = \sum_{j=1}^{J} w_{ijk}$$ where i∈recycling and reuse treatments

and k ∈ final disposal treatments

The amounts of waste generated by an industrial sector, w_{ijk}, were extracted from the waste database. Using the above equations, the amount of the waste flow, x_{mn}, were calculated and the waste flow diagram drawn.

However, at node 2, which is the intermediate treatment node, the calculated values of x_{23} and x_{24} were too small and contrasted to the characteristics of the intermediate treatment facilities. Thus, estimations of these values must be carried out and used in the model. Intermediate treatment facilities consisted of three waste treatments: sorting, incineration and chemical and physical treatments. After the generated wastes, w_{ijk}, are treated using the incineration facility, there will be wastes remaining for reuse and recycling treatment and other wastes remaining for final disposal treatment. These amounts of wastes can be written as the following equations.

Amount of waste from intermediate treatment remaining for reuse and recycle,

$$x_{23} = \alpha_{\mathrm{k}} x_{12}$$

Amount of waste from intermediate treatment remaining for final disposal,

$$x_{24} = \beta_{\mathrm{k}} x_{12}$$

Here, α_{k} *and* β_{k} are the coefficients of the intermediate treatment transformation.

So far, the amount of wastes generated, u_{ij}, and amount of waste flow, x_{mn}, can be calculated from the available waste database. However, these are only the amounts being requested for removal by the registered factories, not the total amounts.

5.1.3 Calculation of industrial waste flow

The industrial waste data collected by the MOI is classified into 107 types of industry, 808 types of waste and 18 types of waste treatment facility. Each waste treatment / disposal plan that was submitted by the registered factories to the MOI must comply with this classification. The waste data from these waste treatment plans were put in the waste database and arranged into three dimensions: industrial sector, type of waste and type of waste treatment, forming like a waste cube.

The authors defined a new smaller waste data set by regrouping the original waste data classifications; the new waste data set consisted of 17 types of industrial sector, 10 types of industrial waste type and 4 types of waste treatment facility. Using the above waste database, the original waste data were retrieved and converted into the new waste data set and then the calculations of the amount of waste generated were easily carried out. Finally, the estimated amounts of annual industrial waste generation, which were obtained from the IDE-JETRO study, were used as total-control indexes in the calculation of the waste amount generations from 1999 to 2004.

5.2 Estimation of industrial waste generation and its flow

To determine the total amount and types of waste generated within the country, the waste data collection system must be capable of gathering all waste permits of every factory in the country. With the current waste management system in Thailand, it is not possible to collect complete and timely industrial waste data that can reflect the current waste situation of the country. Therefore, the estimations of total waste generation from other studies must be employed and used as a reference and combined with the available industrial waste data to obtain useful waste information to help in planning and managing the waste management system of the country.

5.2.1 Estimation of the total waste generation

To estimate the total amount of waste generated as well as the total amount of waste flow, the total amounts of waste generation in Thailand from 1999 to 2004, which were estimated and published in the study of JETRO, were used as a reference. The total control index for year n, T_n, was then calculated as

$$T_n = \frac{W_n}{\sum u_{ij}} \qquad \text{for} \quad n = \text{year 1999 to 2004}$$

where W_n = The total amount of waste generation in Thailand in year n

Let U_{ij} = total amount of waste type j generated by industrial sector i,

X_{mn} = total amount of waste flow from node m to node n,

where m, n = 1, 2, …, 5.

Then, the total amount of waste generated, U_{ij}, and amount of waste flow, X_{mn} can be calculated as

$$U_{ij} = T_n \text{ x } u_{ij} \qquad \text{and} \qquad X_{mn} = T_n \text{ x } x_{mn}$$

5.2.2 Estimation of industrial wastes generation by industrial sector

Let G_i = total amount of waste generated by industrial sector i.

The total amount of wastes generated by industrial sector i, G_i, is then calculated as

$$G_i = \sum_{j=1}^{J} U_{ij} \qquad \text{where } i \in \text{waste generators of industrial sector i.}$$

5.2.3 Estimation of industrial waste generation and waste flow

The waste treatment / disposal plans in 2004 were used as an example for the estimation of the waste generation. The amounts of waste generated were calculated and summed according to the original sector and the disposal treatment facility. The results for the waste flows are shown in **Table 9**. The industrial waste flows are illustrated and shown as a network model in **Fig. 5** below.

Table 9 Calculations of waste flows in 2004 (× 1,000 tons).

Source	Intermediate	Reuse and recycling	Final disposal	Export	Total output
Waste generator	1,397	10,652	2,348	179	14,576
Intermediate	0	946	451	0	1,397
Reuse and recycling	0	0	4	0	4
Final disposal	0	0	0	0	0
Total input	1,397	11,598	2,804	179	15,978
Net flow out	0	11,594	2,804	179	

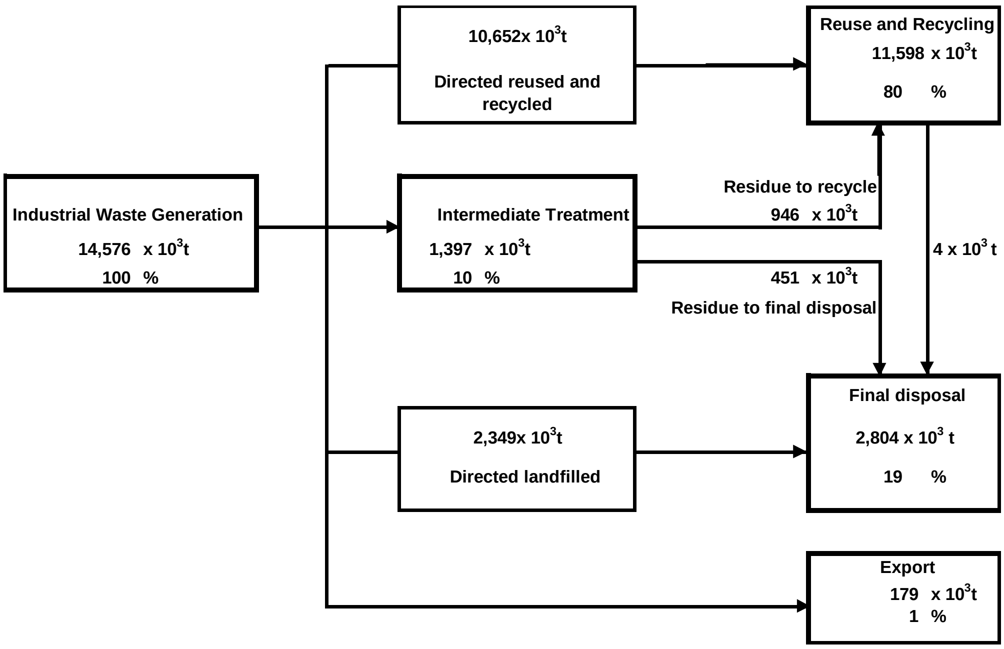

Fig. 5 Industrial waste flow in the fiscal of 2004.

5.2.4 Estimation of industrial wastes disposed by reuse and recycling

Reuse and recycling accounted for 79.57% or 11.598 million tons of waste and was the most used waste treatment method. Reuse and recycling consisted of a number of treatment methods as shown in **Table 10**.

Table 10 Details of reuse and recycling in 2004 (× 1,000 tons).

List of waste treatment methods	Waste amounts in 1,000 tons	% Used
Use as raw material	1,739	15
Composing	188	2
Animal feed	1,597	14
Fuel blending	933	8
Incineration in cement kiln	453	4
Other reuse and recycling	6,689	58

6. Results

Using the industrial waste data collected by the industrial waste data collection system of Thailand together with the waste cube model, the industrial waste management system can be systematically analyzed and much useful waste information can be revealed.

6.1 Amount of waste generation and disposed amount

The annual amounts of waste generation and disposal from 2001 to 2004 were calculated, estimated and compared, as shown in **Fig. 6**.

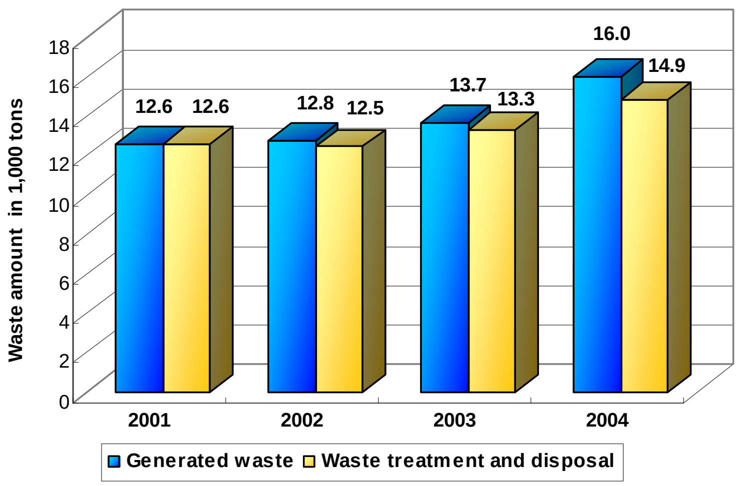

Fig. 6 Amounts of waste generated and disposed from 2001 to 2004.

6.2 Amount of waste generation by industrial sector

The waste generations by the 17 industrial sectors from 2002 to 2004 were regrouped into 4 main groups and are shown in **Fig. 7**.

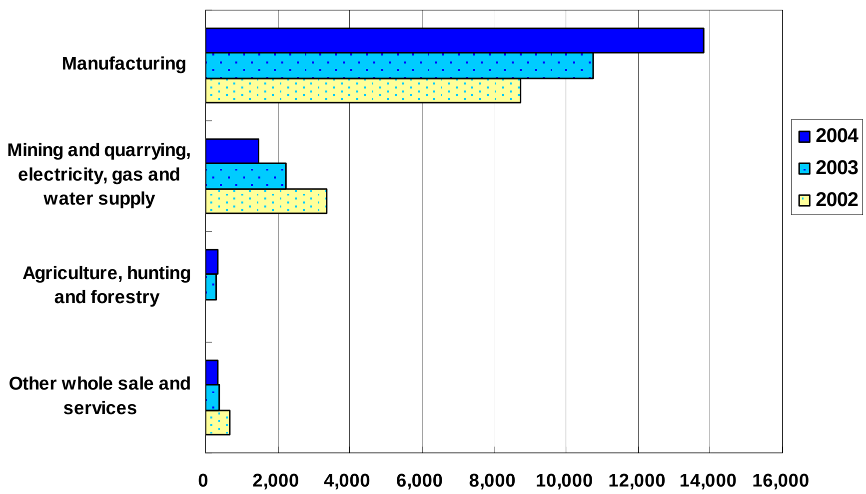

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Fig. 7 Amounts of industrial waste generation by the four industrial sectors.

All 17 industrial sectors were regrouped into 5 bigger groups and the industrial waste generations in 2002, 2003 and 2004 were calculated and distributed according to the new industrial groups, as shown in **Table 11**.

Table 11 Amounts of waste generation by the five industrial sectors from 2002 to 2004.

Industrial sector	Amounts of waste in 1,000 tons			Change in % 2002 - 2004
	2002	2003	2004	
Manufacturing	8,719	10,760	13,827	59%
Mining and quarrying, electricity, gas and water supply	3,368	2,245	1,482	-56%
Agriculture, hunting and forestry	36	310	349	859%
Other whole sale and services	677	386	344	-49%
Construction	N/A	N/A	3	N/A
Total	12,801	13,700	16,005	25%

Table 11 shows the manufacturing sector had the biggest increase in the amount of waste generation, from 8.719 to 13.827 million tons or 58.57%, from 2002 to 2004.

6.3 Amount of waste generation by waste type

The waste generations by waste type from 2002 to 2004 were calculated and estimated and are shown in **Fig. 8**.

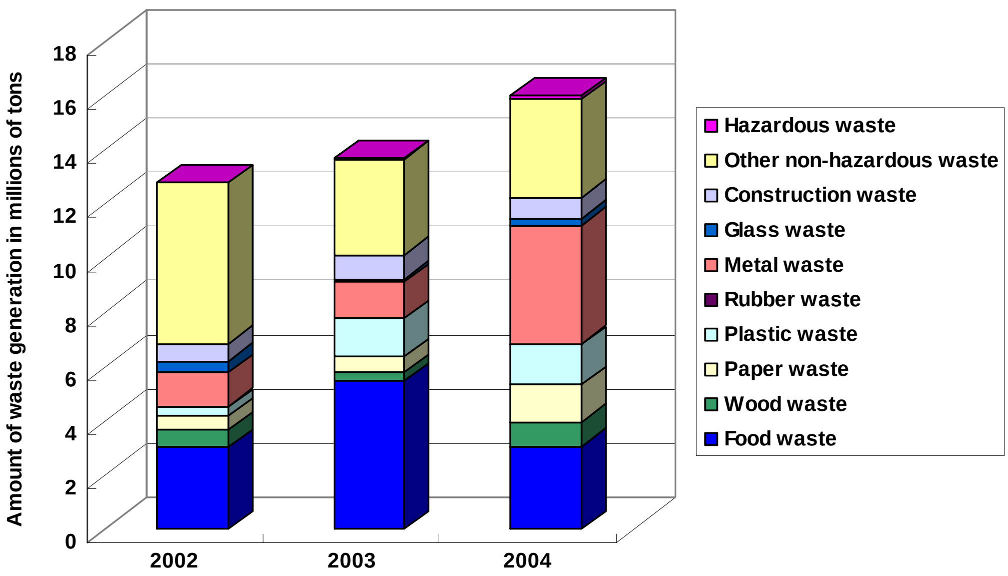

Fig. 8 Amount of industrial waste generation by waste type.

6.4 Amount of industrial waste disposed by waste treatment group

The amounts of industrial waste disposed by each waste treatment group from 2002 to 2004 were calculated and estimated and are shown in **Fig. 9**.

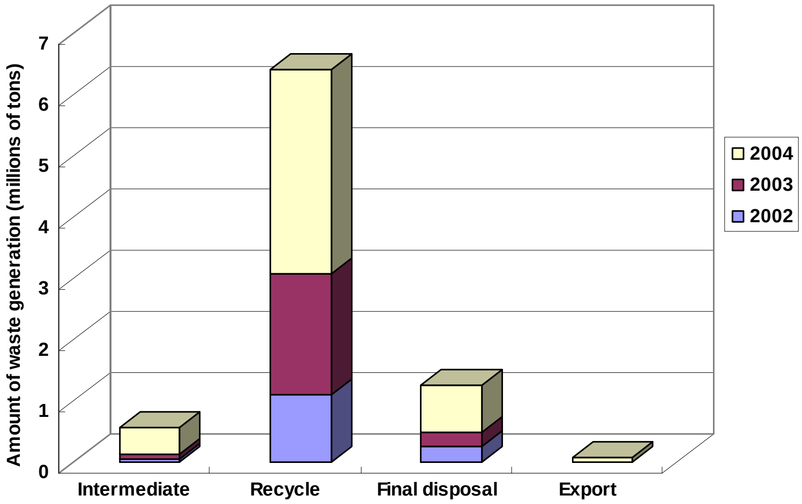

Fig. 9 Amounts of industrial waste disposed by waste treatment groups.

6.5 Amount of industrial waste disposed by reuse and recycle treatment

Reuse and recycling was the most used waste treatment method in Thailand. The amounts of industrial waste disposed by reuse and recycling, for each waste type from 2002 to 2004, were calculated and estimated and are shown in **Fig. 10**. The amounts of industrial waste disposed by six subgroups of reuse and recycling are shown in **Fig. 11**.

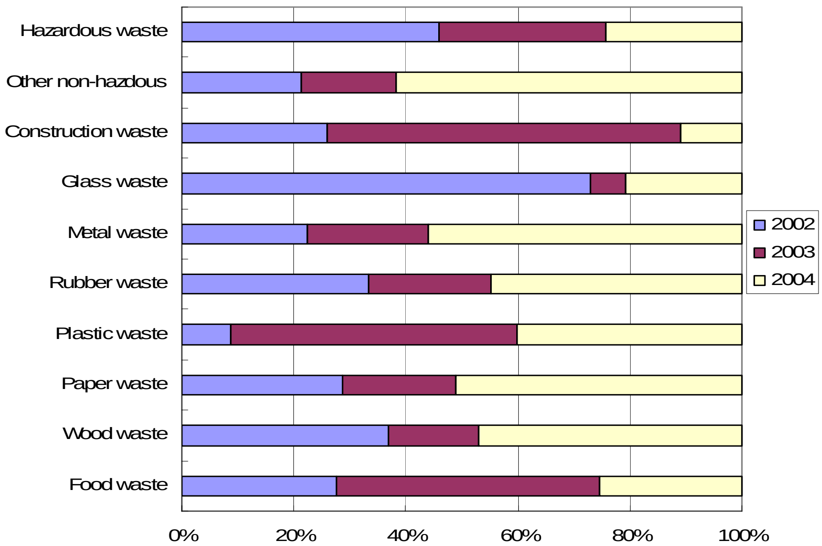

Fig. 10 Amount of industrial waste disposed by reuse and recycling for each waste type.

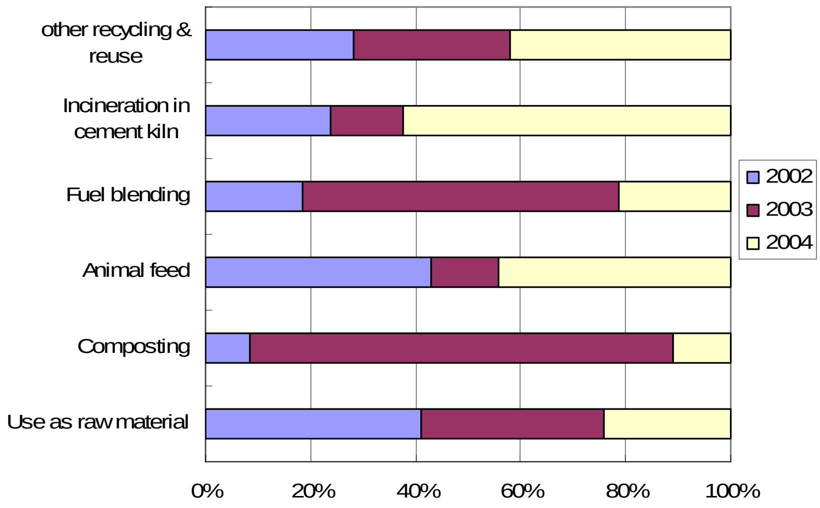

Fig. 11 Amounts of industrial waste disposed by six subgroups of reuse and recycling.

6.6 Discussion of results

The reported industrial waste generation in Thailand fluctuated around 12.61 million tons per year from 1999 to 2002. There was a big increase in waste generation of 11.93% from 2002 to 2004. Most waste, about 77.26% of the total waste, came from the manufacturing sectors. This study shows the manufacturing industry had the largest increase in waste generation, from 8.72 to 13.82 million tons or 58.57%, from 2002 to 2004. Food, metal, plastic and paper waste were the top four industrial wastes in Thailand. The average amounts of these waste types were 33.26%, 16.46%, 7.69% and 5.41% of total waste generation respectively. Waste recycling and reuse was the dominant waste disposal method, accounting for 83.60% of disposal on average. Food and metal wastes were the waste types most disposed of by reuse and recycling (33.26% and 16.46% of total waste production, respectively). The major types of reuse and recycling were producing raw materials, fuel blending, and producing animal feed, which accounted for 21.37%, 13.04% and 10.81% of reuse and recycling respectively.

Total waste generation in Thailand had an interrelationship with economic growth from 1999 to 2004. The relation could be expressed as

$$y = -1.0059+0.0054x$$

with the correlation coefficient $R^2 = 0.7616$

where x = GDP per capita at constant price, in US$, from 1999 to 2004, and
y = total waste generation, in millions of tons, in the corresponding year

The correlation coefficient greater than 0.7 indicated the relationship between total waste generation and the economic growth of Thailand was justified.

7. Conclusions

The main findings from this study are as follows.

(1) The available and currently used industrial waste data collection system in Thailand is appropriate for developing the waste cube model. The developed waste cube model can estimate the total industrial waste generation as well as the total industrial waste flow. The model can be used as an effective tool in managing the waste management system in Thailand.

(2) The industrial waste generation in Thailand has increased every year since 1999 and there was a big increase in industrial waste generation from 2002 to 2004.

(3) Industrial waste flow could show the industrial waste treatment situation in Thailand clearly. It could illustrate the distribution of the usages of waste treatment facilities. Reuse and recycling was the most used waste treatment method in Thailand from 2002 to 2004.

(4) There was a relationship between the economic development (GDP per capita) and industrial waste generation (amount of waste generation) in Thailand as shown in **Fig. 2**. This relationship was shown using the waste generation per GDP per capita. This waste generation index is an international standard that can be used in the comparison of the industrial waste situations for various countries.

This paper shows that with sufficient available industrial waste data and corresponding economic data, the industrial waste flow can be determined and an analysis can be made efficiently using the matrix type model or waste cube model. The greatest difficulty does not relate to the method used but to the waste data and economic data management. In Thailand, these necessary industrial waste and economic data were already collected and prepared by many different organizations. Without good cooperation among these types of organizations, the collection of all necessary data will be a problem. To manage all these data effectively, a waste database is an essential tool that needs to be developed to store all required data. A computer application can then be develop to calculate and construct the industrial waste flow and an analysis of industrial waste flow can be done systematically.

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