# Research on Environmental Design Implementation in Taiwan's Manufacturers Certified by ISO 14001

**Yi-Chan Chung and Chih-Hung Tsai†**

Department of Industrial Engineering and Management
Ta-Hwa Institute of Technology
1 Ta-Hwa Road, Chung-Lin, Hsin-Chu, Taiwan, ROC
Tel: +886-3-5430-466, E-mail: ietch@thit.edu.tw

## Abstract

This research investigates the status of environmental design implementation in Taiwan's industries (Certified by ISO 14001) by employing questionnaire survey. The correlation between the degree of environmental design implementation in Taiwan's industries and the relevant entrepreneurial characteristics are examined. Twenty-six environmental design principles in four phases: design, manufacturing, sales and transportation, and disposal are used to define and assess the current status of environmental design. The data analysis methods applied to this research includes descriptive statistics, T-test, Chi-square test, and single-factor analysis of variance (ANOVA). It is evident that 21 out of the 26 environmental design principles are frequently and consistently employed by the manufacturers in Taiwan. The results indicate that environmental design implementation is becoming mature in Taiwan's industries.

**Key Words:** Environmental Design, Environmental Design Implementation, ISO 14001

## 1. Introduction

Since the International Standardization Organization enacted ISO 14001 environmental management standards in 1996, environmental protection has reached a new milestone, from concept promotion to universal global implementation standards. ISO 14001 environmental management system standards are a general system of design standards, applicable to organizations from various cultural backgrounds, scale, and geographic regions. However, the standards do not impose absolute environmental performance requirements. Therefore, ISO 14001 implementation cannot guarantee immediate environmental performance improvement (Xiang, 1996). Environmental performance improvement can be defined as the relief of environmental challenges. In a narrow sense, environmental performance improvement may be

† Corresponding Author

limited to relief, or elimination of, all kinds of disposal and waste problems. However, every phase of a complete product life cycle (PLC), involves various environmental challenges, such as the selection of raw materials, energy consumption, waste gas emissions, waste water disposal and waste production. Therefore, the fundamental environmental design method considers the environmental challenges at different product life stages and minimizes the total burden to improve environmental performance (Overby, 1990; SETAC, 1991; SETAC, 1993). A product produces various environmental challenges at every stage of its life cycle (raw materials exploration, manufacturing, transportation, sales, use, and disposal). Environmental design minimizes the challenges products and manufacturing processes bring to the environment, health and security based on systematic considerations (Fiksel, 2001). Environmental design will be an important topic in the 21st century and become an integral part of sustainable corporate growth. In the pursuit of economic development and environmental protection, companies should be more focused on effective environmental design activities, thereby realizing the goal of sustainable growth. Design is undoubtedly the step that has the largest impact on products. All of the parameters determined in the design process have a decisive impact on every stage of a product's life cycle (Piasecki, 1995). Traditionally, many manufacturers used 'end-of-pipe pollution control' to solve environmental problems at every stage. However, as many more laws and regulations have been enacted requiring manufacturers be responsible for all product-related environmental costs incurred from manufacturing to disposal, end-of-pipe control will cause duplications in personnel and equipment, thus increasing cost. This in turn will put enterprises in a disadvantageous competitive position. Environmental design measures a product's impact on the environment at different stages of its lifecycle from a macro perspective. This approach reduces the environmental responsibility costs and provides an effective means to improve environmental performance (Bailey, 1990/1991). The initial product and process design stage is the optimum time to present environmental design (Girard and Perras, 1994; Morrs *et al.*, 1995; Stead and Stead, 1994). Environmental design includes two aspects. First, changes in existing products, new product, designs reduction in product disposal and hazardous materials, pollution relief in the use stage. The second stage involves recyclable materials design (Fiksel, 2001; Klassen and Mclaughlin, 1993; Lund, 1993; SETAC, 1993; Starik, 1995). A successful environmental design should consider many functional dimensions such as recyclablity, re-manufacturability, re-usability, disassembility and disposability (Binshan *et al.*, 2001).

Taiwan is an export-orientated country that must pay more attention to the trends in international environmental protection. This is evident from the recent promotion and implementation of ISO 14001 environmental management. It is imperative that environmental design be at the forefront of environmental management. In this research, questionnaires were sent out to 1,200 ISO 14001 certified firms registered with the Taiwan Environmental Management Association and 200 firms qualified for environmental standards registered with the Taiwan Ministry of Economics. This questionnaire surveyed the current status of environment design in Taiwan. This research has three primary goals: (1) investigate the current status of environmental design implemented by manufacturers in Taiwan; (2) discuss the relationship between the degree of environmental design performance and the relevant manufacturer characteristics; and (3) analyze the results and make recommendations for manufacturer reference in future operations.

## 2. Research Methodology

This research identified the current status of environmental design implementation among Taiwan manufactures. The implementation performance was assessed and studied in four phases: design, manufacturing, transportation and sales, and disposal. The source data for this research were collected from 1,200 ISO 14001 certified firms registered with the Taiwan Environmental Management Association and 200 firms qualified for environmental standards registered with the Taiwan Ministry of Economics by November 2003. The researchers used questionnaires to collect the information relating to current environmental design performance. This questionnaire was designed in accordance with the relevant environmental design literature and amended using interviews with experts. The respondents were executive quality control management from various sample manufacturers. Questionnaires were sent by mail. According to the data from the Taiwan Environmental Management Association and Taiwan Ministry of Economics, 1,200 manufacturers were ISO 14001 certified, and 200 manufacturers qualified for environmental standards by November 2003. The statistical measurement scale used in this questionnaire was the 'Nominal Scale' and 'Value' for the basic data in Part One and the motivation and level of implementation for corporate environmental design in Part Two. In Part Three, the degree of environmental design implementation is measured using the "Likert 5 Points Scale", where 5 represents always implemented, 4 represents frequently implemented, 3 represents occasionally implemented, 2 represents rarely implemented, and 1 represents never implemented. This questionnaire divided the environmental design principles into 4 dimensions using 26 topics targeting manufacturers certified using the ISO 14001 quality control system series and environmental protection regulations to measure current corporate environmental design performance. The data analysis methods adopted in this research include descriptive statistics, T-test, Chi-square test, and single-factor analysis of variance.

## 3. Questionnaire Results and Analysis

Questionnaires were mailed to 1,400 manufacturers in November 2005. Three hundred three questionnaires were returned by December 2005. Of these, 290 were valid excluding 13 that were either incomplete or unclear.

### 3.1 Overall Trend Analysis

The descriptive statistical analysis of the data collected from the returned questionnaires reveals the current environmental design implementation status in the involved industries. The descriptive analysis results are shown in Table 1.

**Table 1.** Basic data on the manufacturers in this study

| Basic data item | | Times | (%) |
|---|---|---|---|
| Industry Category | Photo-electricity | 11 | (3.8%) |
| | Semiconductor | 11 | (3.8%) |
| | Electronic | 51 | (17.6%) |
| | Chemistry | 55 | (19.3%) |
| | Textile | 22 | (7.6%) |
| | Food | 13 | (4.5%) |
| | Electric Machinery | 28 | (9.7%) |
| | Machinery | 13 | (4.5%) |
| | Means of Transportation | 17 | (5.9%) |
| | Paper | 13 | (4.5%) |
| | Metal Processing | 14 | (4.8%) |
| | Environmental Protection | 8 | (2.8%) |
| | Steel | 5 | (1.7%) |
| | Construction | 8 | (2.8%) |
| | Other | 20 | (6.9%) |
| Motives For Implementation | Response to Customer Demand | 155 | (53.4%) |
| | Response to Government Policies | 139 | (47.9%) |
| | Suppliers' Requirements | 34 | (11.7%) |
| | Threat from Competition | 51 | (17.6%) |
| | Pressure from Environmental Protection Organizations | 36 | (12.4%) |
| | Pressure from Industrial and Commercial Organizations | 6 | (2.1%) |
| | Image Improvement | 225 | (77.6%) |
| | Product Quality Enhancement | 127 | (43.8%) |
| | Market Development | 90 | (31.0%) |
| | Cost Reduction | 122 | (42.1%) |
| | Profitability Improvement | 86 | (29.7%) |
| | Increased Innovative Capacity | 93 | (32.1%) |

| Basic data item | | Times | (%) |
|---|---|---|---|
| Number of Employees | Below 100 | 86 | (29.7%) |
| | 101~300 | 79 | (27.2%) |
| | 301~500 | 41 | (14.1%) |
| | 501~1,000 | 40 | (13.8%) |
| | 1,001~2,000 | 21 | (7.2%) |
| | Above 2,000 | 23 | (8.0%) |
| Average Revenue for the past three years (NT$) | Less than 60 million | 19 | (6.6%) |
| | 60~300 million | 64 | (22.1%) |
| | 300~500 million | 34 | (11.7%) |
| | 500 million ~1 billion | 42 | (14.5%) |
| | 1~3 billion | 47 | (16.2%) |
| | 3~5 billion | 22 | (7.6%) |
| | Above 5 billion | 62 | (21.3%) |
| Amount of Capital (NT$) | Below 60 million | 42 | (14.5%) |
| | 60 million ~300 million | 74 | (25.5%) |
| | 300 ~500 million | 34 | (11.7%) |
| | 0.5~1 billion | 28 | (9.7%) |
| | 1~3 billion | 34 | (11.7%) |
| | 3~5 billion | 19 | (6.6%) |
| | Above 5 billion | 59 | (20.3%) |

Note: 1. Other industry category includes 2 from cement industry, 1 from agriculture, 2 from stationery, 4 from porcelain and glass industry, 2 from manufacturing, 2 from optical lens manufacturing, 2 from mold manufacturing, 1 from rubber industry, 3 from bath equipment, and 1 from tape industry

2. In this research, 1,400 questionnaires were sent out in November 2005 and 303 were collected by December 2005, of which 290 were valid

### 3.2 Environmental Design Evaluation Indicator Analysis

To examine the environmental design principle implementation level in each phase, the mean and standard deviation of each environmental design principle were calculated to observe the variation and difference. Moreover, the T test was used to test the following hypotheses to provide more accurate detect significant level implementation.

$H_0$: $\mu = 4$

$H_1$: $\mu \neq 4$

The different phase analysis clearly shows (as revealed by T test results in Table 2) that 80.8% of the environmental design principles in this study were often considered (often implemented, $\mu$= 4) by manufacturers (21 out of 26 design principles are often implemented). This

**Table 2.** Analysis of the level of environmental design implementation

| Phase | Design principles | The use of environmental design principle[1] | | | |
|---|---|---|---|---|---|
| | | Mean | Standard Deviation | T-value[2] | P-value[3] |
| Design Phase | Use of recyclable or pollution-free raw materials | 4.1765 | 0.7454 | 4.025 | 0.000 |
| | Use of energy-conserving materials in production | 4.0969 | 0.7846 | 2.099 | 0.037 |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 4.0450 | 0.7871 | 0.972 | 0.332 |
| | Design of products can maximize the efficiency of energy utilization | 4.0830 | 0.8334 | 1.694 | 0.091 |
| | Design of products that release less toxic wastes in their life cycle | 4.6090 | 0.5975 | 17.327 | 0.000 |
| | Design of products with increased lifespan | 4.0346 | 0.9676 | 0.608 | 0.544 |
| | Design of easily-maintainable products | 3.8131 | 1.0896 | -2.915 | 0.004 |
| | Design of easily-recyclable products | 3.9723 | 1.0236 | -0.460 | 0.646 |
| | Design of easily-manufactured products | 4.0173 | 0.9222 | 0.319 | 0.750 |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 4.2215 | 0.7542 | 4.992 | 0.000 |
| | Reducing the release of pollution | 4.4740 | 0.6720 | 11.992 | 0.000 |
| | Reducing the production of wastes | 4.4498 | 0.7157 | 10.685 | 0.000 |
| | Setting up proper waste storage and disposal process | 4.5502 | 0.5937 | 15.753 | 0.000 |
| | Properly dealing with the release of pollution | 4.6021 | 0.6215 | 16.469 | 0.000 |
| | Increasing the renewable rate of disposed energy or heat | 3.8962 | 1.0975 | -1.608 | 0.109 |
| | Eliminating the unnecessary operational procedure in manufacturing process | 4.3114 | 0.7499 | 7.059 | 0.000 |
| | Increasing the utilization of recyclable energy resources such as solar energy | 2.9239 | 1.3390 | -13.663 | 0.000 |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 3.8062 | 1.0593 | -3.110 | 0.002 |
| | Informing customers of the features of environment-friendly products | 3.7889 | 1.0641 | -3.372 | 0.001 |
| | Reducing the usage of package | 3.9689 | 0.8754 | -0.605 | 0.546 |
| | Use of recyclable package | 4.0311 | 0.9368 | 0.565 | 0.572 |
| | Use of bio-decomposable package | 3.4187 | 1.2023 | -8.219 | 0.000 |
| | Optimizing transportation path to save energy | 3.9619 | 0.9835 | -0.658 | 0.511 |
| | Reducing the usage of energy in transportation | 3.8962 | 0.9981 | -1.768 | 0.078 |
| Waste Disposal Phase | Establishing the procedures of recycling wastes | 4.4775 | 0.7456 | 10.887 | 0.000 |
| | Developing proper waste disposal procedure | 4.5744 | 0.6364 | 15.343 | 0.000 |

Note: 1. The measurement is done by Likert 5 Points Scale, where 1 represents never implemented, 2 represents rarely implemented, 3 represents occasionally implemented, 4 represents frequently implemented, and 5 represents always implemented

2. The bigger the absolute value of T statistic, the further the average value is away from 4; the smaller the absolute value of T statistic, the closer the average value is to 4

3. $P < 0.05$ represents that the mean does not equal to 4; $P > 0.05$ represents that the mean equals to 4

result shows that manufacturers have achieved a certain level of actual environmental design implementation.

## 3.3 Correlation and Variance Analysis

In this section, the Chi-square test and Single-Factor analysis are used to analyze the correlation between two variables. If the test statistics are significant, the two variables have a significant impact on each other. We focused on a discussion of the correlation and variance for such variables as the companies' basic data, the companies' motivation for implementing environmental design, and the environmental design principles in different dimensions.

### 3.3.1 Correlation between Basic data and Environmental Design Principles Analysis

The correlation between a company's environmental design implementation level in different dimensions and some specific properties of the basic data concerning the company is studied in this research. Single-factor analysis of variance is the statistical analysis method used for variance analysis. The phases studied include design, manufacturing, sales and transportation, and disposal. This research tested each environmental design principle in every dimension together with the company's basic data in order to determine their correlation. The different phase analysis indicates that the manufacturer's average annual sales, capital amount, and number of employees have a common significant impact on the implementation level of one environmental design principle, the sixth design principle in the manufacturing phase, increasing the renewable rate for wasted energy or heat. Further analysis of this principle through LSD found that larger companies (in terms of sales, capital, and number of employees) exhibited significantly superior performance to that of smaller companies with regard the renewable energy factor (as shown in Tables 3 to 5). Since large companies consume a great deal of energy, an increase in the renewable rate for disposed energy or heat will reduce manufacturing costs and be consistent with the environmental protection trend. This is an environmental design action worth implementing. The industry property category does not affect the implementation level at each stage of environmental design as shown in Table 6. The cooperative technology and capital properties have an evident impact on the third, fourth and ninth environmental design principles in the design phase. These are the products or manufacturing processes whose design reduces raw materials use, products whose design achieves the optimal energy utilization efficiency, and products that are designed for ease of manufacture (as shown in Table 7). Further analysis through LSD shows that those manufacturers in partnership with American or Japanese companies perform significantly better than domestic self-operating manufacturers as their product or manufacturing process designs can reduce raw materials use, obtain optimal energy utilization efficiency, and make products that are easy to manufacture. American and Japanese manufacturers place more emphasis on reducing raw materials use, facilitating production, and improving energy utilization efficiency.

**Table 3.** Single- factor variance analysis of the correlations between the manufacturers' sales revenue and their current environmental design implementation status

| Phase | Design principles | F-statistic | P-statistic | LSD Multi-test |
|---|---|---|---|---|
| Design Phase | Use of recyclable or pollution-free raw materials | 0.494 | 0.813 | |
| | Use of energy-conserving materials in production | 1.017 | 0.414 | |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 0.651 | 0.689 | |
| | Design of products can maximize the efficiency of energy utilization | 1.038 | 0.401 | |
| | Design of products that release less toxic wastes in their life cycle | 0.504 | 0.805 | |
| | Design of products with increased lifespan | 1.139 | 0.339 | |
| | Design of easily-maintainable products | 0.617 | 0.717 | |
| | Design of easily-recyclable products | 1.265 | 0.274 | |
| | Design of easily-manufactured products | 0.355 | 0.907 | |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 0.650 | 0.690 | |
| | Reducing the release of pollution | 1.615 | 0.143 | |
| | Reducing the production of wastes | 1.273 | 0.270 | |
| | Setting up proper waste storage and disposal process | 1.183 | 0.315 | |
| | Properly dealing with the release of pollution | 1.100 | 0.362 | |
| | Increasing the renewable rate of disposed energy or heat | 2.840 | 0.011* | 1, 2, 3, 4 < 7<br>5, 6, 7 > 1 |
| | Eliminating the unnecessary operational procedure in manufacturing process | 0.999 | 0.426 | |
| | Increasing the utilization of recyclable energy resources such as solar energy | 0.568 | 0.756 | |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 0.562 | 0.761 | |
| | Informing customers of the features of environment-friendly products | 0.530 | 0.785 | |
| | Reducing the usage of package | 0.428 | 0.860 | |
| | Use of recyclable package | 0.915 | 0.485 | |
| | Use of bio-decomposable package | 1.376 | 0.224 | |
| | Optimizing transportation path to save energy | 1.389 | 0.219 | |
| | Reducing the usage of energy in transportation | 1.163 | 0.326 | |
| Waste Disposal Phase | Establishing the procedures of recycling wastes | 0.997 | 0.428 | |
| | Developing proper waste disposal procedure | 0.504 | 0.805 | |

Note: 1. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

2. LSD 1 ~ 7 represents manufacturers' sales revenue respectively: (1) below 60 million; (2) 60 million ~300 million; (3) 300~500 million; (4) 0.5~1 billion; (5) 1~3 billion; (6) 3~5 billion; (7) above 5 billion

**Table 4.** Single- factor variance analysis of the correlations between the manufacturers' capital amount and their current environmental design implementation status

| Phase | Design principles | F-statistic | P-statistic | LSD Multi-test |
|---|---|---|---|---|
| Design Phase | Use of recyclable or pollution-free raw materials | 0.931 | 0.473 | |
| | Use of energy-conserving materials in production | 0.745 | 0.614 | |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 0.495 | 0.812 | |
| | Design of products can maximize the efficiency of energy utilization | 0.731 | 0.625 | |
| | Design of products that release less toxic wastes in their life cycle | 0.505 | 0.804 | |
| | Design of products with increased lifespan | 0.692 | 0.656 | |
| | Design of easily-maintainable products | 0.527 | 0.788 | |
| | Design of easily-recyclable products | 0.768 | 0.596 | |
| | Design of easily-manufactured products | 0.170 | 0.985 | |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 1.009 | 0.420 | |
| | Reducing the release of pollution | 1.119 | 0.351 | |
| | Reducing the production of wastes | 1.225 | 0.279 | |
| | Setting up proper waste storage and disposal process | 1.360 | 0.231 | |
| | Properly dealing with the release of pollution | 1.429 | 0.204 | |
| | Increasing the renewable rate of disposed energy or heat | 2.369 | 0.033* | 1, 2, 3, 4 < 7<br>1, 2, 3 < 6 |
| | Eliminating the unnecessary operational procedure in manufacturing process | 0.447 | 0.847 | |
| | Increasing the utilization of recyclable energy resources such as solar energy | 0.669 | 0.674 | |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 0.650 | 0.690 | |
| | Informing customers of the features of environment-friendly products | 0.827 | 0.550 | |
| | Reducing the usage of package | 0.965 | 0.449 | |
| | Use of recyclable package | 0.164 | 0.986 | |
| | Use of bio-decomposable package | 0.821 | 0.554 | |
| | Optimizing transportation path to save energy | 1.371 | 0.226 | |
| | Reducing the usage of energy in transportation | 1.362 | 0.230 | |
| Waste Disposal hase | Establishing the procedures of recycling wastes | 1.216 | 0.298 | |
| | Developing proper waste disposal procedure | 1.677 | 0.126 | |

Note: 1. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

2. LSD 1 ~ 7 represents manufacturers' sales revenue respectively: (1) below 60 million; (2) 60 million ~300 million; (3) 300~500 million; (4) 0.5~1 billion; (5) 1~3 billion; (6) 3~5 billion; (7) above 5 billion

**Table 5.** Single- factor variance analysis of the correlations between the number of employees and the current environmental design implementation status

| Phase | Design principles | F-statistic | P-statistic | LSD Multi-test |
|---|---|---|---|---|
| Design Phase | Use of recyclable or pollution-free raw materials | 1.258 | 0.282 | |
| | Use of energy-conserving materials in production | 1.537 | 0.178 | |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 0.682 | 0.637 | |
| | Design of products can maximize the efficiency of energy utilization | 0.824 | 0.533 | |
| | Design of products that release less toxic wastes in their life cycle | 0.373 | 0.867 | |
| | Design of products with increased lifespan | 0.712 | 0.615 | |
| | Design of easily-maintainable products | 0.539 | 0.747 | |
| | Design of easily-recyclable products | 0.537 | 0.748 | |
| | Design of easily-manufactured products | 0.496 | 0.779 | |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 0.190 | 0.996 | |
| | Reducing the release of pollution | 1.023 | 0.404 | |
| | Reducing the production of wastes | 1.503 | 0.189 | |
| | Setting up proper waste storage and disposal process | 1.518 | 0.184 | |
| | Properly dealing with the release of pollution | 1.872 | 0.099 | |
| | Increasing the renewable rate of disposed energy or heat | 2.272 | 0.040* | 6 > 1, 2, 3 |
| | Eliminating the unnecessary operational procedure in manufacturing process | 0.318 | 0.902 | |
| | Increasing the utilization of recyclable energy resources such as solar energy | 1.124 | 0.348 | |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 0.426 | 0.831 | |
| | Informing customers of the features of environment-friendly products | 0.795 | 0.554 | |
| | Reducing the usage of package | 0.768 | 0.573 | |
| | Use of recyclable package | 0.773 | 0.570 | |
| | Use of bio-decomposable package | 0.223 | 0.952 | |
| | Optimizing transportation path to save energy | 1.340 | 0.247 | |
| | Reducing the usage of energy in transportation | 1.489 | 0.193 | |
| Waste Disposal Phase | Establishing the procedures of recycling wastes | 0.829 | 0.530 | |
| | Developing proper waste disposal procedure | 1.766 | 0.120 | |

Note: 1. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

2. LSD 1 ~ 6 represents the number of employees respectively: (1) below 100; (2) 101~300; (3) 301~500; (4) 501~1,000; (5) 1,001~2,000; (6) above 2,000

**Table 6.** Single- factor variance analysis of the correlations between the different industry manufacturing categories and their current environmental design implementation status

| Phase | Design principles | F-statistic | P-statistic | LSD Multi-test |
|---|---|---|---|---|
| Design Phase | Use of recyclable or pollution-free raw materials | 0.524 | 0.918 | |
| | Use of energy-conserving materials in production | 1.173 | 0.296 | |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 0.731 | 0.742 | |
| | Design of products can maximize the efficiency of energy utilization | 1.719 | 0.052 | |
| | Design of products that release less toxic wastes in their life cycle | 1.284. | 0.217 | |
| | Design of products with increased lifespan | 0.969 | 0.486 | |
| | Design of easily-maintainable products | 0.734 | 0.740 | |
| | Design of easily-recyclable products | 0.552 | 0.900 | |
| | Design of easily-manufactured products | 0.568 | 0.889 | |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 0.510 | 0.927 | |
| | Reducing the release of pollution | 0.901 | 0.558 | |
| | Reducing the production of wastes | 0.926 | 0.532 | |
| | Setting up proper waste storage and disposal process | 0.488 | 0.939 | |
| | Properly dealing with the release of pollution | 0.900 | 0.559 | |
| | Increasing the renewable rate of disposed energy or heat | 1.372 | 0.166 | |
| | Eliminating the unnecessary operational procedure in manufacturing process | 0.542 | 0.907 | |
| | Increasing the utilization of recyclable energy resources such as solar energy | 0.662 | 0.811 | |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 1.170 | 0.298 | |
| | Informing customers of the features of environment-friendly products | 0.882 | 0.579 | |
| | Reducing the usage of package | 0.952 | 0.504 | |
| | Use of recyclable package | 1.148 | 0.316 | |
| | Use of bio-decomposable package | 1.274 | 0.223 | |
| | Optimizing transportation path to save energy | 0.716 | 0.758 | |
| | Reducing the usage of energy in transportation | 0.509 | 0.927 | |
| Waste Disposal Phase | Establishing the procedures of recycling wastes | 0.366 | 0.983 | |
| | Developing proper waste disposal procedure | 0.396 | 0.975 | |

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

**Table 7.** Single- factor variance analysis of the correlations between the technology and capital collaboration and the current environmental design implementation status

| Phase | Design principles | F-statistic | P-statistic | LSD Multi-test |
|---|---|---|---|---|
| Design Phase | Use of recyclable or pollution-free raw materials | 0.885 | 0.449 | |
| | Use of energy-conserving materials in production | 2.384 | 0.069 | |
| | Design of products or manufacturing processes that can reduce the usage of raw materials | 2.823 | 0.039 | 2, 3 > 1 |
| | Design of products can maximize the efficiency of energy utilization | 2.693 | 0.046 | 2, 3 > 1 |
| | Design of products that release less toxic wastes in their life cycle | 1.558 | 0.200 | |
| | Design of products with increased lifespan | 1.119 | 0.342 | |
| | Design of easily-maintainable products | 1.943 | 0.123 | |
| | Design of easily-recyclable products | 1.524 | 0.208 | |
| | Design of easily-manufactured products | 2.698 | 0.046 | 2, 3 > 1 |
| Manufacturing Phase | Reducing the use of energy resources when manufacturing or assembling products | 0.880 | 0.452 | |
| | Reducing the release of pollution | 1.624 | 0.184 | |
| | Reducing the production of wastes | 0.828 | 0.479 | |
| | Setting up proper waste storage and disposal process | 1.883 | 0.133 | |
| | Properly dealing with the release of pollution | 1.436 | 0.232 | |
| | Increasing the renewable rate of disposed energy or heat | 1.971 | 0.118 | |
| | Eliminating the unnecessary operational procedure in manufacturing process | 0.862 | 0.461 | |
| | Increasing the utilization of recyclable energy resources such as solar energy | 0.551 | 0.648 | |
| Sales and Transportation Phase | Proactively advertising the characteristics of environment-friendly products | 0.597 | 0.617 | |
| | Informing customers of the features of environment-friendly products | 0.866 | 0.459 | |
| | Reducing the usage of package | 1.878 | 0.133 | |
| | Use of recyclable package | 1.181 | 0.317 | |
| | Use of bio-decomposable package | 0.488 | 0.691 | |
| | Optimizing transportation path to save energy | 1.246 | 0.293 | |
| | Reducing the usage of energy in transportation | 1.165 | 0.323 | |
| Waste Disposal Phase | Establishing the procedures of recycling wastes | 0.108 | 0.956 | |
| | Developing proper waste disposal procedure | 1.009 | 0.389 | |

Note: 1. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

2. LSD 1 ~ 4 represents the technology and capital cooperation between domestic and foreign companies respectively: (1) self-financed; (2) cooperate with U.S manufacturers; (3) cooperate with Japan manufacturers; (4) others

### 3.3.2 Correlation Analysis of Motivations for Implementation

1. Correlation analysis between Motivations for Implementation and Basic Data: In this section, we will study if the difference in manufacturers' basic data will cause significant variations in a manufacturers' motivation to implement environmental design. The manufacturers' technology and capital cooperation does not have any significant impact on various motivations for environmental design implementation. However, the difference in industry category has a significant impact on the motivation for "responding to customer needs" (as shown in Table 8). Further statistical analysis results reveal that the electronics, semiconductor, and optical industries, which contribute the largest share to Taiwan's exports, appear to have a stronger motivation to implement environmental design in response to customer requirements. The reason is that the high-technology-intensive, export-oriented electronics, semiconductor, and optical industries are under the greatest pressure from the international green trade. Three factors, number of employees, capital amount, and sales, are directly related to the manufacturers' scale, have significant impact on the motivation for "adapting to government policy". According to further statistical analysis results, companies with larger scale (in terms of number of employees, capital amount, and sales) are clearly more motivated to implement environmental design in terms of "adapting to government policy". Large industries are more sensitive to the pressure of complying with government policies and regulations due to their intent in building competitive advantages in a timely fashion. The Ministry of Legislation of the Republic of China passed the "Green Procurement Article" on May 21, 1998, which took effect on May 27, 1999. This Article requires governments and government agencies to give priority to procuring products approved by the government for environmental protection, to other products with the same or similar functions, and allows for no more than a 10% price difference. This applies equally to products or raw materials whose manufacture, use and disposal processes satisfy renew ability, recyclability, low population and energy conservation requirements. This Article encourages governments and government agencies to take advantage of their extraordinary purchasing power and to prioritize the procurement of green products that impose less adverse effects on the environment. This in turn challenges the procurement behavior of large companies and becomes a major motivation for large companies to implement environmental design.
2. Correlation analysis between Motivations for Implementation and Average Implementation Performance in Different Phases: In this section, we discuss whether manufacturers' motivations for implementation significantly affect the average implementation performance in different phases. Based on the analysis of variance (as shown in Table 9), the motivations of "responding to customer demand", "threat from competition", "adapting to government policies", "pressure from environmental protection", "suppliers' requirements", and "pressure from industrial and commercial organizations", do not affect the

**Table 8.** Variance analysis for the correlations between implementation motives and manufacturers' basic data

| Basic data | | Sales Revenue | Capital | Industry Category | Number of Employees | The cooperation of Technology and Capital |
|---|---|---|---|---|---|---|
| Motive 1 | $\chi^2$ | 6.807 | 5.614 | 13.441 | 2.486 | 0.712 |
| | p-value | 0.339 | 0.468 | 0.005** | 0.779 | 0.870 |
| Motive 2 | $\chi^2$ | 9.935 | 7.726 | 14.081 | 5.674 | 4.553 |
| | p-value | 0.127 | 0.259 | 0.444 | 0.291 | 0.208 |
| Motive 3 | $\chi^2$ | 4.538 | 7.440 | 13.183 | 2.806 | 2.012 |
| | p-value | 0.604 | 0.282 | 0.512 | 0.730 | 0.570 |
| Motive 4 | $\chi^2$ | 8.124 | 6.387 | 17.257 | 7.712 | 1.624 |
| | p-value | 0.229 | 0.381 | 0.243 | 0.251 | 0.654 |
| Motive 5 | $\chi^2$ | 13.391* | 3.343 | 12.961* | 12.957* | 1.840 |
| | p-value | 0.021 | 0.765 | 0.044 | 0.044 | 0.606 |
| Motive 6 | $\chi^2$ | 8.554 | 8.795 | 19.042 | 3.272 | 0.111 |
| | p-value | 0.200 | 0.185 | 0.163 | 0.658 | 0.990 |
| Motive 7 | $\chi^2$ | 5.694 | 5.156 | 8.755 | 6.784 | 2.062 |
| | p-value | 0.458 | 0.524 | 0.846 | 0.237 | 0.560 |
| Motive 8 | $\chi^2$ | 3.297 | 6.323 | 18.780 | 3.534 | 4.495 |
| | p-value | 0.771 | 0.388 | 0.174 | 0.618 | 0.213 |
| Motive 9 | $\chi^2$ | 7.977 | 7.265 | 14.929 | 3.726 | 2.382 |
| | p-value | 0.240 | 0.297 | 0.383 | 0.590 | 0.497 |
| Motive 10 | $\chi^2$ | 5.775 | 8.559 | 10.930 | 5.674 | 2.444 |
| | p-value | 0.449 | 0.200 | 0.692 | 0.339 | 0.485 |
| Motive 11 | $\chi^2$ | 5.001 | 3.579 | 5.931 | 6.207 | 3.027 |
| | p-value | 0.544 | 0.733 | 0.968 | 0.287 | 0.387 |
| Motive 12 | $\chi^2$ | 4.812 | 3.116 | 7.507 | 2.368 | 1.061 |
| | p-value | 0.568 | 0.794 | 0.913 | 0.796 | 0.787 |

Note: 1. *p < 0.1; **p < 0.05; ***p < 0.01

2. The motives are in order as (1) response to customer demand, (2) threat from competition, (3) image improvement, (4) cost reduction, (5) response to government policies, (6) pressure from environmental protection, (7) product quality improvement, (8) increased profitability, (9) suppliers' requirements, (10) pressure from industrial and commercial organizations, (11) new market development and (12) enhanced innovative capability

**Table 9.** Variance analysis for the correlations between implementation motivations and average implementation performance in different dimensions

| Implementation Motivations / Phase | | Design Phase | Manufacturing Phase | Sales and Transportation Phase | Waste Disposal Phase |
|---|---|---|---|---|---|
| Response to Customer Demand | F | 2.168 | 0.937 | 0.898 | 1.773 |
| | p-value | 0.142 | 0.334 | 0.344 | 0.184 |
| Variance | | | | | |
| Threat from Competition | F | 0.317 | 0.451 | 0.319 | 0.882 |
| | p-value | 0.574 | 0.503 | 0.574 | 0.362 |
| Variance | | | | | |
| Image Improvement | F | 10.166** | 8.732** | 10.675** | 6.221** |
| | p-value | 0.002 | 0.003 | 0.001 | 0.013 |
| Variance | | Yes > No | Yes > No | Yes > No | Yes > No |
| Cost Reduction | F | 4.251* | 1.670 | 2.236 | 4.083* |
| | p-value | 0.041 | 0.197 | 0.136 | 0.045 |
| Variance | | Yes > No | | | Yes > No |
| Response to Government Policies | F | 0.922 | 0.522 | 0.243 | 1.297 |
| | p-value | 0.338 | 0.471 | 0.622 | 0.256 |
| Variance | | | | | |
| Pressure from Environmental Protection | F | 0.326 | 0.504 | 1.480 | 0.273 |
| | p-value | 0.568 | 0.478 | 0.225 | 0.602 |
| Variance | | | | | |
| Product Quality Improvement | F | 10.033** | 3.823 | 13.593*** | 0.277 |
| | p-value | 0.002 | 0.052 | 0.000 | 0.634 |
| Variance | | Yes > No | | Yes > No | |
| Increased Profitability | F | 4.721* | 1.232 | 1.912 | 0.614 |
| | p-value | 0.031 | 0.268 | 0.168 | 0.434 |
| Variance | | Yes > No | | | |
| Suppliers' Requirements | F | 1.235 | 0.033 | 0.628 | 0.207 |
| | p-value | 0.267 | 0.856 | 0.429 | 0.649 |
| Variance | | | | | |
| Pressure from Industrial and Commercial Organizations | F | 0.495 | 0.709 | 0.366 | 0.009 |
| | p-value | 0.482 | 0.401 | 0.545 | 0.925 |
| Variance | | | | | |
| New Market Development | F | 0.014 | 0.211 | 4.374* | 0.184 |
| | p-value | 0.907 | 0.646 | 0.038 | 0.668 |
| | | | | Yes > No | |
| Enhanced Innovative Capability | F | 17.817** | 13.274*** | 17.018*** | 1.831 |
| | p-value | 0.000 | 0.000 | 0.000 | 0.177 |
| | | Yes > No | Yes > No | Yes > No | |

Note: 1. *p < 0.1; **p < 0.05; ***p < 0.01

2. "Yes > No" represents the average implementation performance of the companies with this implementation motivation is better than that of those without this motivation

average level of performance at each stage. However, the motivation for improving corporate reputation affects the average level of performance in four phases: design phase (F=10.166, P=0.002), manufacturing phase (F=8.732, P=0.003), sales and transportation phase (F=10.675, P=0.001), wastes disposal phase (F=6.221, P=0.013). The motivation of cost reduction affects the average level of performance in two phases: design phase (F=4.251, P=0.041) and waste disposal phase (F=4.083, P=0.045). The product quality improvement motivation affects the average performance level in two phases: the design phase (F=10.033, P=0.002) and sales and transportation phase (F=13.593, P=0.000). The increasing profit motivation affects the average performance level in the design phase (F=4.721, P=0.031). The exploiting new markets motivation affects the average performance level in the sales and transportation phases (F=4.374, P=0.038). The enhanced innovative capability motivation affects the average performance level in three phases: the design phase (F=17.817, P=0.000), manufacturing phase (F=13.274, P=0.000), sales and transportation phase (F=17.018, P=0.000). The LSD test shows that proactive motivations such as "corporate image enhancement", "cost reduction", "product quality improvement", "increase in profitability", "new market development", and "enhanced innovative capability" could help manufactures improve their average performance level in the respective stages involved. However, passive motivations such as "responding to customer demand", "threat from competition", "adapting to government policies", "pressure from environmental protection', "suppliers' requirements", and "pressure from industrial and commercial organizations", do not influence the average performance level in the respective stages involved.

# 4. Conclusions and Recommendations

## 4.1 Conclusions

The prime motivation for environmental design implementation considered by Taiwanese companies is corporate image enhancement. This is confirmed by 77.6% of the companies in this study (as shown in Table 1). This indicates that the major motivation for Taiwanese companies to implement environmental design is proactive and self-motivated in an effort to improve their corporate image through environmental design. The current environmental design implementation status in Taiwanese companies was discussed based on four phases and twenty-six design principles. Among these design principles, twenty-one were well implemented.

1. Design Phase: There are eight primary environmental design principles that were most often and consistently implemented by manufacturers in Taiwan. They are "using recyclable or pollution-free raw materials", "using energy-conserving materials in production", "product or manufacturing process designs that reduce raw materials use", "product designs that maximize energy utilization efficiency", "product designs that reduce toxic waste dis-

posal during the product's life cycle", "designs that extend the products' lifespan", "product designs that are easy to recycle", and "product designs that are easy to manufacture". The "product designs that are easy to maintain" has seldom been taken into account. However, the difference in the amount of capital, number of employees, industry category, and sales have no impact on implementing the above eight principles. The differences in technology and capital cooperation causes variations in the implementation of the third, fourth and ninth principles in the design phase; "product or manufacturing process designs that can reduce raw materials use", "product designs that can maximize the energy utilization efficiency", and "product designs that are easy to manufacture". American and Japanese manufacturers place more emphasis on reducing raw materials use, products that are easy to manufacture, and improving energy utilization efficiency.

2. Manufacturing Phase: The environmental design principles most often implemented by Taiwanese manufacturers are: "reduce energy usage during manufacturing or product assembly", "to reducing pollution release", "reducing waste production", "setting up proper waste storage and disposal procedures", "properly handling pollution release", "increasing disposed energy or heat renewable rate", and "eliminating unnecessary manufacturing process operational procedures". The principle of "increasing renewable energy use" has rarely been taken into consideration. Large manufacturers in terms of capital amount, number of employees, and sales demonstrate superior performance in implementing the principle of "increasing disposed energy or heat renewable rate".
3. Sales and Transportation Phase: The environmental design principles most often implemented by Taiwanese manufacturers are: "reducing product packaging", "using recyclable packaging", "optimizing transportation paths and saving energy", and "reducing transportation energy use". Other environmental design principles have rarely been taken into consideration. Furthermore, the difference in manufacturer scale, industry category, technology and capital cooperation were not related to the implementation performance of the above principles.
4. Waste Disposal Phase: The environmental design principles most often implemented by Taiwan's manufacturers include: 'setting up procedures for recycling disposed products and materials", and 'establishing proper waste disposal procedures'. The difference in manufacturer scale, industry category, and technology and capital cooperation was not related to the implementation of these principles.

## 4.2 Recommendations

The results of this research show that environmental design implementation has become mature in Taiwan. Twenty-one out of twenty-six (80.8%) environmental design principles are frequently and consistently implemented by Taiwan manufacturers. At the beginning of the twenty-first century, the environment was identified alongside price, quality, and delivery date as one of the four essential factors considered by purchasers. Environmental management implementation has become essential to company survival in the global market. The previous analysis shows that Taiwan manufactures do not perform well in terms of "easy to maintain product design", "increasing the utilization of recyclable energy resources", "advertising and informing customers of the characteristics of environment-friendly products", and "using bio-degradable packaging". We recommend that manufacturers design products that are easy to maintain to increase customer satisfaction, and gradually increase research and development into recyclable energy resources. Manufacturers should also take initiative in marketing "green products", helping customers understand the characteristics of environmentally friendly products, and use more bio-degradable packaging to avoid environmental pollution. Generally speaking, large-size manufacturers have been implementing environmental design principles at a reasonable level. Currently, medium and small-sized manufacturers comprise the majority of companies across Taiwan and are not as competitive as large-size manufacturers. Due to the limited human, financial, and material resources, their implementation performance is not satisfactory. The future trends for purchase and consumption of green products creates the need for the government to develop incentive policies and programs to help companies implement environmental design.

## References

1. Bailey, P. E.(1990/1991), "Life-Cycle Costing and Pollution Prevention," *Pollution Prevention Review*, Vol. 1, pp. 27-39.
2. Binshan, L., Charlotte, A. J., and Chang-Tseh, Hsieh(2001), "Environmental Practices and Assessment: A Process Perspective," *Industrial Management and Data Systems*, Vol. 101, No. 2, pp. 71-80.
3. Fiksel, J.(2001), Design for Environment: Creating Eco-efficient Products and Processes, New York: McGraw-Hill.
4. Girard, G. and Perras, C.(1994), Green Supply Chain Management: from Europe to the USA, Paper presented at the National Meeting of ORSA/TIMES, Boston.
5. Klassen, R. and Mclaughlin, C.(1993), "TQM and Environmental Excellence in Manufacturing," *Industrial Management and Data Systems*, Vol. 93, No. 6, pp. 14-22.
6. Lund, R. T.(1993), Remanufacturing. in Klein, J.A. and Miller, J.G. (Eds), The American Edge: Leveraging Manufacturing's Hidden Assets, McGraw-Hill, New York, pp. 225-240.
7. Morrs, E. H. M., Mulder, D. F., and Vergragt, P. J.(1995), Transformation Strategies towards More Sustainable Industrial Production System: A Case Study of the Zinc Production Industry, Paper presented at the Fourth International Conference of the Greening of Industry Network, Toronto.

8. Overby, C.(1990), Design for the Entire Life-Cycle: A New Paradigm? In Proceedings of the International Conference on Pollution Prevention (EPA/600/9-90/039).
9. Piasecki, B. W.(1995), Corporate Strategy, John Wiley & Sons, Inc.
10. SETAC(1991), A Technical Framework for Life-Cycle Assessment.
11. SETAC(1993), Guidelines for Life Cycle Assessment: A code of Practice.
12. Starik, M.(1995), "Research on Organization and the Natural Environment: Some Paths We Have Travelled, the Field Ahead," *Research in Corporate Social Performance and Policy*, Suppl, pp. 1-41.
13. Stead, J. G. and Stead, W. E.(1994), Implementing Sustainability Strategies: What are Organizations Doing? Paper presented at the Annual Meeting of the International Association for Business, Hilton Head, SC.
14. Xiang Gu.(1996), "Strategies for Taiwan Industries to Respond to ISO 14001 Environmental Management Standards," *Industry Pollution Prevention*, Vol. 15, Third Issue, pp. 96-106.