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The Relationship between Environmental Input and Output Indicators by the Robust Fitting Method

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Abstract: Environmental protection has aroused much public concern in recent years. Environmental management systems (EMS) have been advocated for all economic sectors. The construction industry contributes to environmental destruction by generating pollution and is by no means exempt from EMS. The greatest obstacle, in carrying out EMS, is the lack of objective performance evaluation criteria. In 1999, ISO 14031 environmental performance evaluation (EPE) was introduced for assessing the environmental performance related to management and operational systems. Unfortunately these measures are not adopted in the construction industry in some parts of the world, including Hong Kong. However, there have been a number of economic sectors implementing EMS and EPE including electronic engineering, telecommunications, mineral exploration, oil and gas industries and power generation. The construction industries reluctance is due to the self-initiation nature of the scheme lacking any external stimulus and the thin profit margins achieved by most construction firms. The high investment cost of the scheme deters contractors from the implementation of it although the application of EPE does offer many benefits. This paper attempts to develop a series of input (*EOI*) and output (*EPI*) indicators for EPE and measure their relations by using a robust fitting method. The results show that the defined *EOIs* correlate strongly with *EPIs*. Therefore, EPE can help in identifying areas for continuous improvement, and can provide an early indication of the environmental performance for an organization.

Keywords: Environmental management, Environmental performance evaluation, Operational levels, Environmental protection, Construction industry, Building economics, Robust fitting methods

Introduction

Environmental protection is an important issue around the world (Tse, 2001). The environmental impact of buildings over the entire life cycle process has been recognized as a serious problem for the construction industry (Morledge & Jackson, 2001; Polster *et al.*, 1996). Some researchers argued that the site environmental assessment could be an essential tool for parties within a construction organization (Clayton Group Services, 2001; Crawley & Aho, 1999; Ren, 2000). Implementation of ISO 14000 is suggested for all industries including construction (International Organization of Standardization, 2006). ISO 14000 deals with EMS, which is defined as part of the overall management system that includes organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving and reviewing, and maintaining the environmental policy (Clements, 1996; Tan, Ofori, & Briffett, 1999). The standard requires a company to evaluate its current and potential environmental exposures in terms of their impact and compliance with local legislation (Jasch, 2000). ISO 14000 EMS can provide a framework for achieving and demonstrating a desired level of environmental performance (Tam, Tam, & Zeng, 2002; Wu, 2003). However it is not easy for a company to establish an environmental performance evaluation system, an essential tool for achieving continual improvement of environment (Sanvicens & Baldwin, 1996). Thus it is necessary to implement ISO 14031 EPE for effective environmental management (Kuhre, 1998).

ISO 14031 is designed to provide measurable objectives and targets for monitoring and evaluating the performance against different organizations with the purpose of promoting the use of EPE in improving the environmental performance (Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente, 2006; Kuhre, 1998). Also to measure, analyze, assess, report and communicate an organization's environmental performance (Ren, 2000). It allows an organization to determine its ongoing performance in meeting environmental criteria continuously to help reduce the environmental impact. Ways to prevent pollution can be identified and used to improve overall performance of the business

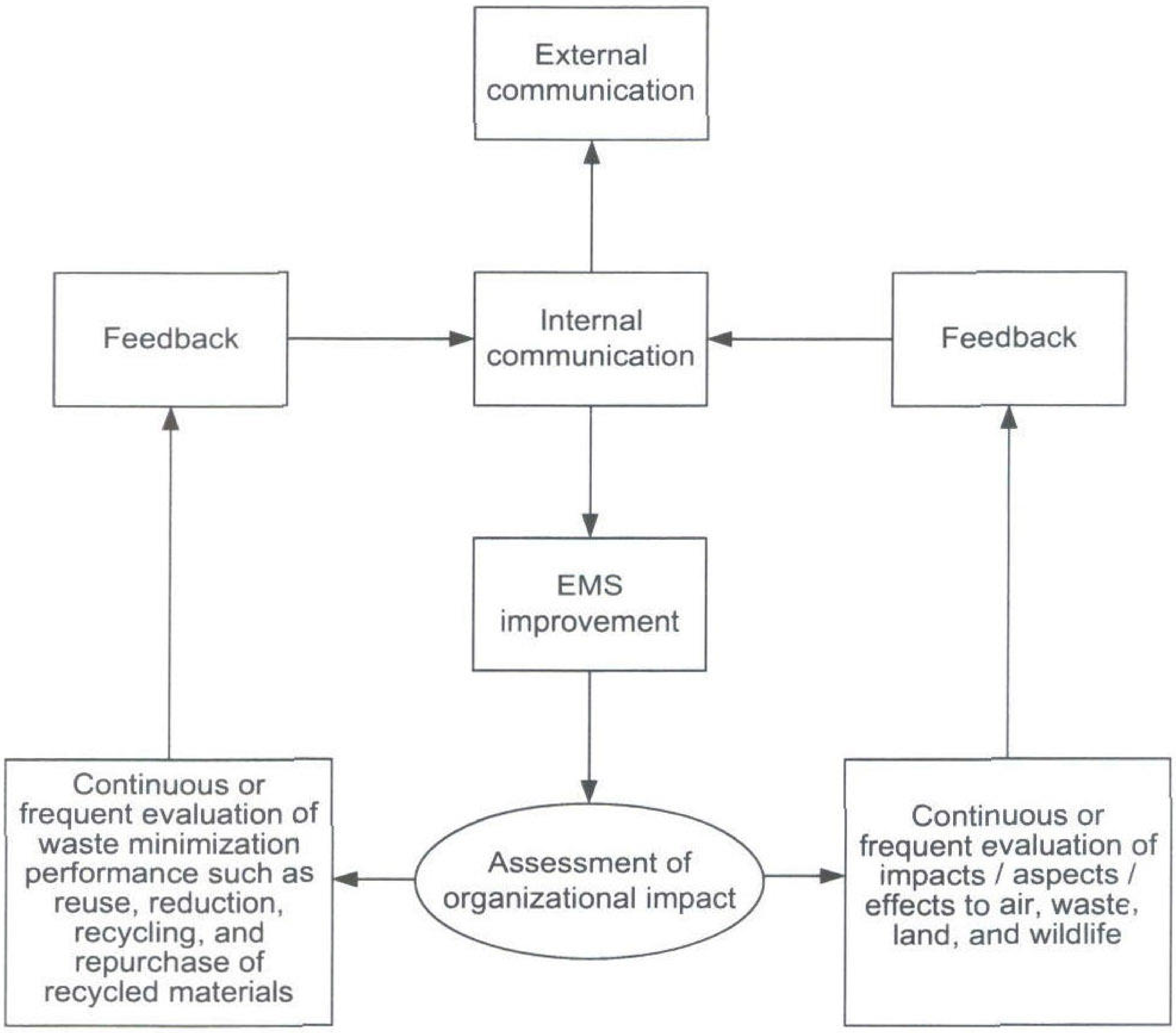

***Figure 1:** Overview of EPE (Kuhre, 1998).*

(Tibor, 1996). Meyer (Meyer, 2001) opinioned that EPE could be implemented at different stages of projects and could compare the environmental performance through company environmental reports (Hopkinson, James, & Sammut, 2000). ANSI (American National Standards Institute, 2006), Jasch (Jasch, 2000) and Kuhre (Kuhre, 1998) defined EPE as an internal management process to provide reliable and verifiable information on an ongoing basis to determine and improve organizational goals, objectives and targets on the environmental performance set by the management of the organization. Tron (Tron, 1995) pointed out that consistent, relevant and comparable environmental performance information for management control is seen as a prerequisite for the long-term healthy development of an organization.

Research Objectives

This paper aims to evaluate the effectiveness of EPE by correlating the input factors at the operational level (*EOIs*) and the output factors of the environmental performance outcome (*EPIs*) for construction in Hong Kong. The objectives are to:

- Highlight the importance of EPE in evaluating environmental performance
- Identify a series of input (*EOIs*) and output (*EPIs*) assessment indicators
- Examine the relationships between *EOIs* and *EPIs* in the context of construction by using robust fitting methods
- Provide some implications from the analysis into the environmental management for the construction industry

Relationship between EPE and EMS

EMS is used to establish environmental policies, objectives, and targets. EPE is used to generate valuable information, against which management can then use to set specific, measurable goals and objectives to the various stages of the EMS process, including planning, implementation, monitoring, measurement, and management review. Although EPE is one of the elements in EMS, EPE can be used to assess the environmental performance in any situations. During the process of EMS, EPE provides valuable, ongoing input to the various stages including planning, implementation, monitoring, measurement, and management review (Tibor, 1996) and helps measure the targets. EPE alone can be used to support the objective of continuous improvement in the environmental performance. The overview of EPE is shown in Figure 1 (Kuhre, 1998).

The Robust Fitting Method

The robust fitting method uses an iteratively re-weighted least-squares algorithm, with the weights at each iteration being calculated by applying the bisquare function to the residuals from the previous iteration. This algorithm gives lower weight to points that do not fit well. The results are less sensitive to outliers in the data as compared with ordinary least-squares linear regression (see Figure 2). This methodology is conveniently supported by the MATLAB programming package including all plots and mathematical equations.

The effectiveness of the robust fitting linear regression method is best demonstrated by using an example. Consider a set of data points that are generated by using simulations. The input vector x_i is a column array of values 1 to 10. The output y_i is given as a function of x_i with some added random noise. Linear regression is then applied to fit the data using the least-squares method and the robust fitting method. The results of both methods are shown in Figure 2 in which the robust-fitting method clearly gives a better fit than the least-squares method as the former gives less weight to erroneous points caused by noise or measurement errors.

Developing Performance Indicators

Environmental performance evaluation (EPE) is a critical tool of EMS in checking, reviewing, monitoring, and evaluating environmental performance of organizations. It is an ongoing process of collection and assessment of data and information to provide a current evaluation of performance, as well as trends over time (Jasch, 2000; Tam, Deng, & Zeng, 2002). A primary role of EPE is to provide a comprehensive assessment of the environmental performance of a construction project. Environmental indicators focus on the use of tangible measures to attempt the evaluation of performance. They offer significant and standardized data of environmental performance, not only as assessment but also in comparison with different site conditions (Benneth & James, 1999a; Jasch, 2000). By monitoring the indicators, regular evaluation and target control can be exercised since they can highlight any adverse trends in the process of environmental control (Tam, Tam *et al.*, 2002). Since operational performance is an important and indispensable element in evaluating environmental performance, this paper focuses on evaluation factors of EPE at an operational level, as site environmental assessment is essential for parties within a construction organization (Clayton Group Services, 2001; Crawley & Aho, 1999; Ren, 2000). The following; highlights the Environmental Operational Indicators (*EOIs*) and Environmental Performance Indicators (*EPIs*) used in this study.

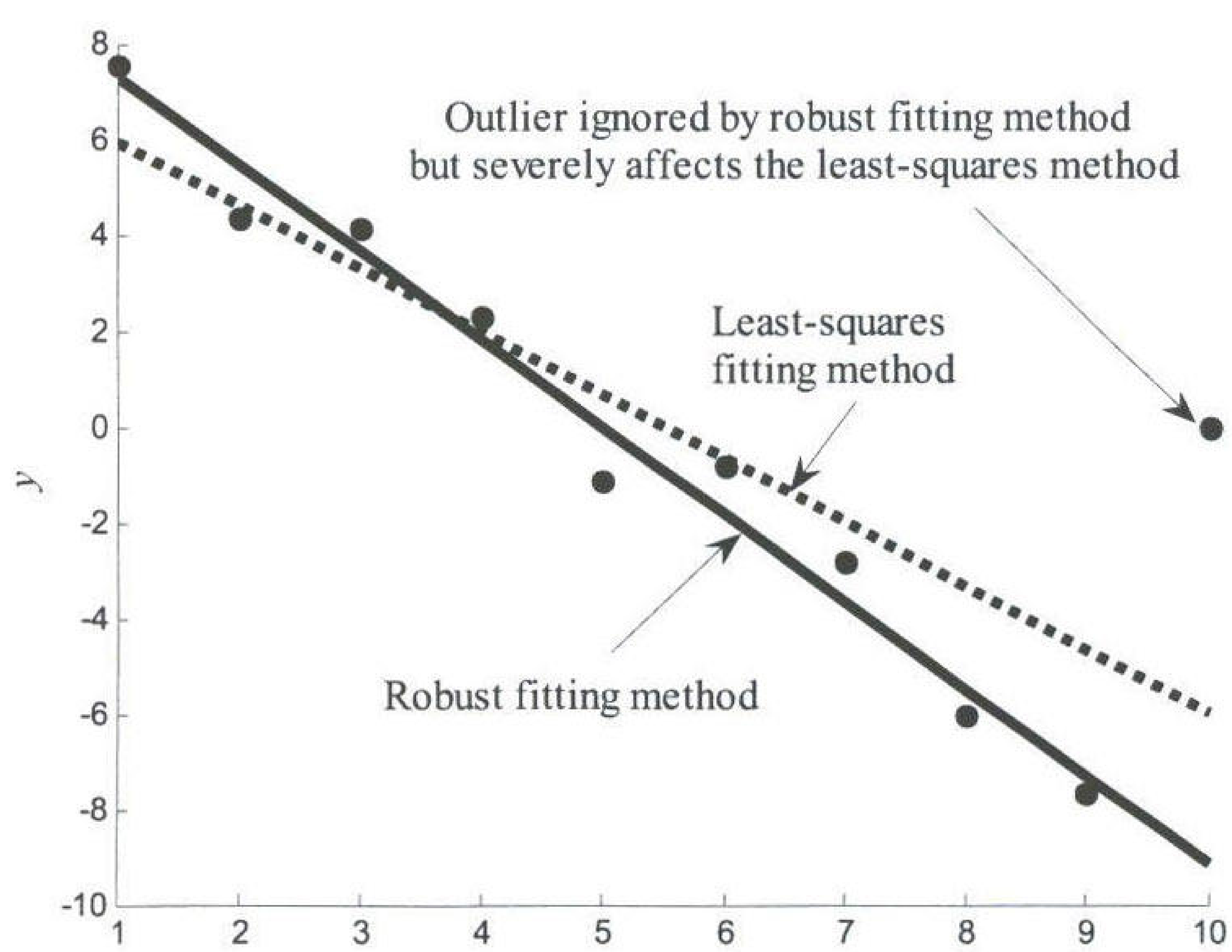

Figure 2: *A comparison of robust-fitting and least-squares linear regression methods (Press, Teukolsky, Vetterling, & Flannery, 1994).*

Environmental Operational Indicators (EOIs)

Organizational operations are defined as being physical facilities and equipment, and the supply to and delivery from them, during the production processes (Jasch, 2000). *EOIs* are used to assess the major inputs including resources, energy and other aspects of facilities and equipment, which relate to:

i) design, operation, and maintenance
ii) materials, energy, products, services, waste, and emissions
iii) supply of materials, energy and services to, and the delivery of products, services and waste, associated with the organization's physical facilities and equipment

In this study, some parameters for *EOIs* have been suggested; for example, (i)environmental site planning can provide an early preparation for the overall environmental performance (Jasch, 2000; Kuhre, 1998); (ii)energy consumption should be included in the evaluation criteria of *EOIs* (Benneth & James, 1999a; Clayton Group Services, 2001; International Organization of Standardization, 2006; Jasch, 2000; Kuhre, 1998; Meyer, 2001; Tibor, 1996); (iii)effective maintenance of equipment helps improve operating efficiency and so operational environmental performance (Benneth & James, 1999a, 1999b; Hong Kong Building Environmental Assessment Method (HK-BEAM), 1999).

There is no doubt that air, noise, sewage and waste are the four major environmental problems and should be given considerable attention to improve environmental performance (Hong Kong Government - Environmental Protection Department, 2006). Input of services used to prevent and to minimize the generation of these four subjects should be considered (Bachas & Tomaras, 1994; Benneth & James, 1999a, 1999b; Clayton Group Services, 2001; Jasch, 2000; Kuhre, 1998). In addition, waste indicators should also be included as they are highly visible phenomena and their targets can be set and easily understood (Benneth & James, 1999a, 1999b). Based on the above, eight indicators (*EOIs*) for inputting operational measures are derived as follows.

EOI-1: Environmental site planning. Site planning is critical in determining and improving the performance of on-site activities which allows better arrangement of activities in respect of labour, plant and equipment, materials, time, cost (Jasch, 2000; Kuhre, 1998). Devising a plan that outlines the environmental management program and the operational practices on construction sites can streamline operations, cut costs, and improve environmental performance. EOI-11: Initial site planning is the sub-indicator.

EOI-2: Energy consumption. Energy is required to support all operations, such as use of construction plants and temporary lighting systems (Benneth & James, 1999a, 1999b; Jasch, 2000). It is necessary to understand the consumption of energy during construction activities (Henderson & McAdam, 2000; Tibor, 1996). EOI-21: Monitor of energy usage is the sub-indicator.

EOI-3: Maintenance of equipment. The environmental performance of construction can influence many aspects of facilities and equipment. For instance, regular maintenance of equipment can often dramatically reduce the generation of emissions and help improve operating efficiency (Benneth & James, 1999a, 1999b; Hong Kong

Building Environmental Assessment Method (HK-BEAM), 1999). EOI-31: Quality of maintenance is the sub-indicator.

EOI-4: Air pollution control. Air pollution has increased in our environment, which affect the respiratory system, reduce visibility, lead to dirty clothing and buildings, and increase the rate of corrosion. Construction activities generate a lot of dust and significantly contribute to air pollution. This situation needs to be controlled by EOI-41: Water sprays for minimizing airborne dust particles, and EOI-42: Mitigation measures to the generation of polluted air (Chen, Li, & Wong, 2000).

EOI-5: Noise pollution control. High-density developments, such as Hong Kong, make noise which is one of the critical construction concerns (Cole, 2000). Noise is an inevitable phenomenon resulting from construction work, in which piling is the nosiest activity. Therefore its impact needs to be reduced, EOI-51: Time management and EOI-52: Mitigation measures to noise levels are necessary.

EOI-6: Water pollution control. Construction activities pollute water and use it inefficiently (Hong Kong Productivity Council, 2006). It is necessary to encourage and educate the staff in EOI-61: Monitor of water usage; EOI-62: Water reusing and recycling systems; and EOI-63: Wastewater treatment.

EOI-7: Waste pollution control. The amount of waste is increasing at a fast rate (Hong Kong Government - Environmental Protection Department, 2006). According to the Environmental Protection Department (Hong Kong Government - Environmental Protection Department, 2006), the construction industry generated about 32,710 tons of C&D waste per year in 1998, nearly 15% above the figure in 1997. Inconsistent with the continuous development of economics and infrastructure, people's awareness of waste reduction is always low on construction sites, which aggravates the situation. As a result, excessive loss of materials and improper waste management is common. EOI-71: Purchasing management (Hong Kong Housing Authority, 2002), EOI-72: Waste reuse and recycling (Lawson *et al.*, 2001; Poon, 1997), EOI-73: Green construction technology (Chen *et al.*, 2000) and EOI-74: Chemical waste treatment (Tilford, Jaeslskis, & Smith, 2000) are the sub-indicators.

EOI-8: Ecological control. Ecological impact is not common for building projects in Hong Kong but can be significant for civil engineering projects. Ecological impact means any disturbance to the pre-existing conditions such as topsoil, trees and vegetation and living habitats (Construction Industry Research and Information Association, 1999). EOI-81 – Degree of efforts in reducing ecological impact – is the sub-indicator. It can be determined by measuring the effort to cope with the potential ecological impacts.

Environmental Performance Indicators (EPIs)

EPIs need to be developed to reflect the output performance of a project, which are used to evaluate the efficiency and effectiveness of environmental management systems (Canadian Institute of Chartered Accountants, 1994). On-site activities such as site cleanliness do directly affect environmental performance. Second, the regulatory compliance should be included in *EPIs* (Jasch, 2000; Tam, Tam *et al.*, 2002; Thoresen, 1999; White & Zinkl, 1999) since the legislation sets the minimum standard for environmental protection. Jasch (Jasch, 2000) pointed out that environmental auditing activities could also provide quality documentation information for controlling and monitoring environmental performance. In summarizing the previous research, five main indicators (*EPIs*) for output performance are proposed:

EPI-1: Site environment. Site environment including cleanliness and tidiness can determine the environmental performance. For example, poor positioning and maintenance of storage areas for materials always result in accidental damages. Proper control and documentation on material flow can minimize material wastage. EPI-11: Overall site environment is the sub-indicator.

EPI-2: Regulatory compliance. There are a number of regulations and ordinances related to environmental protection in Hong Kong (Hong Kong Government - Environmental Protection Department, 2006). The EPE program helps assess the achievement in environmental regulatory requirements (Benneth & James, 1999a, 1999b; Jasch, 2000; Kuhre, 1998; Meyer, 2001). EPI-21: Number of prosecutions received; EPI-22: Number of complaints/warnings received; and EPI-23: Amount of fines and penalties paid are the sub-indicators.

EPI-3: Auditing activities. Auditing activities provide information on the performance of the system. Further, construction organizations need to provide sufficient preparations for pre-auditing, auditing and post-auditing activities (Jasch, 2000) through which it can improve the operational system. EPI-31: Non-conformance report and EPI-32: Report of marginal cases put under observation, provide relevant knowledge in understanding the performance on auditing activities.

EPI-4: Waste generation. Waste generation is always the main concern for any organization. and through environmental management, levels can be lowered. Therefore, EPI-41: Monthly waste generation (in tons) should be considered.

EPI-5: Accident rates. Quality, environmental and safety are the main constraints for a construction project (Shen & Tam, 2002). Among them, safety is of the highest priority as it directly affects human life. Therefore, EPI-51: Accident rate (per 1,000 mandays) should be considered on site.

Interviewing Project Managers

After identifying the input and output indicators (*EOIs* and *EPIs* respectively), the relationships among them were assessed. A sample of forty-nine construction projects managed by five large-sized construction firms was studied. Forty-nine project managers were interviewed and all *EOIs* and *EPIs* were clearly explained to them.. All the interviewed project managers were engaged in all levels of on-site activities and had site experience of at least fifteen years. As the interviewees are experienced project managers and they are involved in the overall project management, they can provide the best knowledge on the projects regarding the environmental management issues. Their expertise, regarding environmental management, is tabulated in Table 1.

To measure the comparative results of the forty-nine construction projects based on the information given by the project managers thaeywere asked to choose an appropriate degree of importance for each indicator (*EOIs* and *EPIs*). A rating scale of 1 (least important) to 7 (most important) was used according to the operational measures and the environmental performance adopted in the projects.

Table 1: Details of the interviewed construction projects.

Project Number	Project Type	Location	Contract Sum	Construction Firm
1	PBH	K	150 millions (M)	A
2	PBH	HKI	119M	A
3	PH	K	5M	A
4	PH	K	470M	A
5	PH	HKI	600M	A
6	PH	HKI	10M	A
7	CM	NW	418M	A
8	CM	NW	142M	A
9	S	K	43M	A
10	PBH	HKI	306M	B
11	PBH	NW	260M	B
12	PH	NW	180M	B
13	PH	HKI	213M	B
14	CM	NW	63M	B
15	CM	NW	95M	B
16	CP	K	63M	B
17	I	K	5M	B
18	S	K	17M	B
19	PBH	HKI	90M	C
20	PBH	HKI	48M	C
21	PH	NW	65M	C
22	PH	K	148M	C
23	CM	K	68M	C
24	CM	HKI	29M	C
25	I	HKI	48M	C
26	I	NW	37M	C
27	I	NW	79M	C
28	S	K	68M	C
29	PBH	NW	159M	D
30	PBH	HKI	36M	D
31	PBH	NW	79M	D
32	PH	K	58M	D
33	PH	HKI	94M	D
34	PH	HKI	284M	D
35	CP	NW	147M	D
36	CP	K	97M	D
37	I	K	260M	D
38	I	NW	248M	D
39	PBH	HKI	278M	E
40	PBH	HKI	169M	E
41	PBH	HKI	79M	E
42	PBH	K	94M	E
43	PH	NW	349M	E
44	PH	NW	179M	E
45	PH	NW	297M	E
46	CM	K	69M	E
47	CP	K	37M	E
48	I	K	59M	E
49	S	HKI	68M	E

Notes:
Project type: PBH – Public housing; PH – Private housing; CM – Commercial; CP – Composite building; I – Industrial; S – School Location: K – Kowloon; HKI – Hong Kong Island; NW – New Territories

Results

The robust-fitting method is used to establish mathematical relationships among input and output indicators with the following advantages

- Be able to estimate the performance of a particular output based on the given input indicators
- Be able to predict the value of a particular output indicator;
- Be able to identify the most dominant input indicator(s) that can result in satisfactory output performance. From that, more emphasis can be focused on the dominant input indicators
- To simplify the work of managers and organizations in long-term investment
- Enable organisations to control effectively the output indicators by lowering the weight on less-dominant input indicators and increasing more weight on more-dominant input indicators.

The robust-fitting linear regression method is used to mathematically link the same set of input and output indicators. The main advantage of this method is that it assigns a lower weight to outliers that are considered as measurement errors or noise. As a result, a better fit to the data can be achieved. Equations (1) to (8) mathematically describe the relationship among the output indicators and input indicators. The R^2 factors of all equations are estimated to assess the goodness-of-fit of the method applying to each output indicator based on the given inputs.

(1)EPI-11 = 0.2870EOI-11 - 0.1241EOI-21 + 0.1437EOI-31 + 0.0649EOI-41 + 0.0902EOI-42 + 0.0557EOI-51 + 0.3456EOI-52 - 0.2041EOI-61 - 0.0919EOI-62 + 0.0118EOI-63 - 0.0812EOI-71 + 0.1902EOI-72 + 0.0752EOI-73 + 0.4374EOI-74 - 0.1202EOI-81 (with R Square of 0.99)

(2)EPI-21 = -0.0831EOI-11 + 0.1637EOI-21 - 0.3762EOI-31 - 0.3091EOI-41 + 0.2054EOI-42 + 0.0991EOI-51 - 0.2808EOI-52 + 0.0325EOI-61 + 0.2172EOI-62 - 0.0803EOI-63 + 0.2620EOI-71 - 0.2798EOI-72 - 0.1135EOI-73 - 0.1876EOI-74 + 0.0895EOI-81 (with R Square of 0.98)

(3)EPI-22 = -0.2443EOI-11 - 0.2135EOI-21 + 0.1556EOI-31 - 0.0698EOI-41 - 0.3799EOI-42 - 0.1538EOI-51 - 0.1370EOI-52 + 0.3290EOI-61 + 0.2340EOI-62 - 0.0753EOI-63 - 0.1512EOI-71 + 0.4247EOI-72 + 0.0985EOI-73 - 0.3137EOI-74 + 0.0388EOI-81 (with R Square of 0.99)

(4)EPI-23 = -0.1138EOI-11 + 0.1076EOI-21 - 0.2368EOI-31 - 0.1747EOI-41 + 0.1372EOI-42 + 0.0960EOI-51 - 0.1716EOI-52 + 0.0733EOI-61 + 0.1216EOI-62 - 0.1100EOI-63 + 0.2475EOI-71 - 0.2372EOI-72 - 0.0432EOI-73 - 0.1104EOI-74 + 0.0691EOI-81 (with R Square of 0.97)

(5)EPI-31 = -0.4104EOI-11 + 0.0630EOI-21 - 0.3601EOI-31 - 0.5230EOI-41 - 0.3749EOI-42 + 0.4186EOI-51 - 0.1717EOI-52 - 0.4423EOI-61 + 0.8759EOI-62 -

0.0431EOI-63 + 0.6806EOI-71 + 0.7597EOI-72 - 0.0300EOI-73 - 0.2529EOI-74 - 0.7343EOI-81 (with R Square of 0.99)

(6) EPI-32=0.0304EOI-11+0.2856EOI-21-0.3065EOI-31 + 0.2836EOI-41 - 0.2999EOI-42 - 0.3404EOI-51 - 0.3928EOI-52 - 0.0414EOI-61 + 0.3566EOI-62 + 0.0205EOI-63 - 0.1657EOI-71 + 0.3422EOI-72 + 0.4520EOI-73 - 0.1404EOI-74 + 0.2685EOI-81 (with R Square of 0.99)

(7) EPI-41=-1.6740EOI-11+0.9179EOI-21+2.4328EOI-31 + 2.9321EOI-41 - 2.4342EOI-42 - 1.3383EOI-51 - 12.3228EOI-52 + 11.5250EOI-61 + 0.6660EOI-62 - 1.5464EOI-63 + 0.6320EOI-71 + 4.2996EOI-72 - 8.2585EOI-73 - 1.9137EOI-74 + 6.8380EOI-81 (with R Square of 0.99)

(8) EPI-51=0.3851EOI-11+4.1705EOI-21+0.6068EOI-31 + 1.3474EOI-41 + 1.8506EOI-42 - 0.2591EOI-51 - 4.0959EOI-52 - 0.6672EOI-61 + 1.9631EOI-62 - 0.8706EOI-63 - 3.2431EOI-71 + 3.0415EOI-72 + 0.0862EOI-73 + 0.7523EOI-74 - 1.0677EOI-81 (with R Square of 0.99)

From Eq (1), it can be noted that *EOI–74 chemical waste treatment* is the dominant factor on *EPI–11 overall site performance* with the regression coefficient of 0.4374. From one of the interview discussions with a project manager, it was highlighted that chemical materials need to be continuously taken care of using storage management and waste treatment. This project wants to lower chemical waste that is sent for special treatment before being dumped to landfill, incurring a high dumping charge. Further, if one can provide efficient chemical waste management, the other environmental management can be easily dealt with using the experience gained from chemical waste management. Therefore, *EOI–74 chemical waste treatment* directly affects the overall site performance.

From Eqs(2) and (4), *EOI–31 maintenance of equipment* is one of the dominant factors affecting the output performance *EPI–21 prosecutions received* and *EPI–23 fines and penalties paid* with regression coefficients of 0.3762 and 0.2368 respectively. This result is consistent with the interview discussions with the project managers. They explained that noise pollution is the main element, rather than air, water and waste pollution, which caused prosecution. As noise pollution is the main concern from the nearby sensitive parties, if construction activities cause high noise pollution, the company will receive prosecutions or fines and penalties are then applied. Therefore, regular maintenance of equipment is important for efficient operation and to control effectively their noise generation.

From Eqs (5) and (6), *EOI–72 waste reuse and recycling* is one of the main factors affecting the output performance *EPI–31 non-conformance auditing report* and *EPI–32: auditing report of marginal cases* with regression coefficients of 0.7597 and 0.3422 respectively. Waste is considered to be a major pollution problem contributing to about 38% along with noise, air and water pollution (Hong Kong Government - Environmental Protection Department, 2006). Thus, if waste reuse and recycling is carried out effectively, then auditing performance can be improved.

From Eq (7), it is clear that *EPI–41* is strongly affected by *EOI-52: mitigate measure of noise pollution control* with regression coefficient of 12.3228. From the interview with site managers, this relationship can be laterally viewed as effective control of noise levels creating a better working environment for workers on site and for the surroundings as less complaints from noise-sensitive parties are filed, thus reducing waste generation. The use of more efficient machinery can significantly lower noise level, resulting in a lower waste level.

From Eq (8), it is clear that the accident rate is also dependent on *EOI-52: mitigate measure of noise pollution control* with the regression coefficient of 4.095. As explained earlier, the use of better and well maintained equipment instead of old and insufficient equipment results in lower waste generation and a lower accident rate. It should also be noted that the *EOI-21 energy consumption* possesses an inverse effects to those of *EOI-52: mitigate measure of noise pollution control*, in which the effects of both indicators can cancel each other out. Under this condition, the accident rate is dependent on *EOI-72 waste reuse and recycling* with the regression coefficient of 3.0415. The cancellation of *EOI-21 energy consumption* and *EOI-52: mitigate measure of noise pollution control* occurs when too-expensive equipment is used to minimise the noise level this is not unusual in the construction industry. This situation can be referred to as saturation in noise control, i.e. beyond a certain standard in special circumstances; better equipment cannot be used to improve the noise level.

It is clear that the robust-fitting method provides satisfactory fitting to the data with R^2 factors of all equations are in the range of 0.97 and 0.99, meaning that these equations can be effectively used to predict the results of output indicators. Individual coefficients can also be used to identify dominant input indicators with respect to a particular output indicator. From that, it is possible to reduce the number of input indicators, resulting in a simpler measurement process of analyzing input and output indicators.

Conclusion

Construction and demolition activities can easily generate pollution and affect the environment. To manage these, Environmental Management Systems (EMSs) can be implemented. However, there is no evidence regarding the effectiveness of such systems. Environmental performance evaluation (EPE) is then suggested to make regular assessment on sites at operational levels. EPE provides information about the achievement of the environmental policy so as to enable the organization to direct its resources in meeting the environmental criteria and identify ways for improvement. To support the applications of EPE, a set of input (*EOIs*) and output (*EPIs*) indicators has been developed to provide information on environmental operational performance.

The *EOIs* so identified are:

i) Environmental Site Planning
ii) Energy Consumption
iii) Maintenance of Equipment
iv) Air Pollution Control
v) Noise Pollution Control
vi) Water Pollution Control
vii) Waste Pollution Control
viii) Ecological Control;

and the EPIs are:

i) Site Environmental
ii) Regulatory Compliance
iii) Auditing Activities
iv) Waste Generation
v) Accident Rate.

By studying the correlations between *EOIs* and *EPIs*, the effectiveness of these input and output factors are evaluated. From the above analysis and discussions, the following points and observations can be concluded:

- The robust fitting method is effective in establishing mathematical relationships among input and output indicators in environmental management
- There is a close relationship between input and output indicators in predicting environmental performance

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