ENVIRONMENTAL ASSESSMENT BY POWER SPECTRUM

Vivian W. Y. Tam[1] and Khoa N. Le[1]
Griffith School of Engineering, Griffith University,
PMB 50 Gold Coast Mail Centre, QLD 9726, Australia.
Email: v.tam@griffith.edu.au

[1] Both authors have identical contributions on this paper.

ABSTRACT

Environmental Performance Assessment (EPA) is a critical tool of the EMS in checking, reviewing, monitoring and evaluating environmental performance of organizations. This paper identifies the most important EPA criterion in a set of criteria developed by Tam *et al* [1, 2] using novel spectral methods. From that, effective ways on improving environmental performance and preventing further damage to the environment can be devised for organizations in the construction industry. In particular, the correlation of the most dominant criterion can be found which further enhances environmental performance of organizations. This paper also shows that not only improvement on environmental performance of organisations can be achieved by identifying the most dominant criterion, but also their efficiency, productivity and customer satisfaction. The power spectral method has been widely used in the field of signal processing for many decades and it is believed that these have never been employed in the field of environmental management. This paper shows the effectiveness and validity of these methods in the field of environmental management.

Keywords: Environmental Management, Environmental Performance Assessment, Criteria, Power Spectra, Bispectra

1. INTRODUCTION

With the growing awareness of environmental issues and increased concern over the deterioration of our environment, studies on impacts of construction activities to the environment have become popular in the last decade [3-6]. Previous studies have identified ten major sources of pollution generated by construction activities: energy consumption; dust and gas emission; noise distribution; waste generated; water discharge; water usage; unnecessary building consumption; pollution by building materials; land usage; and the use of natural resources [7-9]. Out of these, waste generated from the actual building and demolition of construction projects amounts to a large proportion of environmental waste [10]. Indeed, construction processes and their resultant waste have caused concern over the public heath and the environment.

The Hong Kong Government launched the Green Manager Scheme in 1995, requiring every government department to appoint a Green Manager in managing the environmental performance of individual organizations to ensure the environmental performance reached the required standard [11]. As a re-echo to the scheme, all sectors including construction have started committing to environmental issues. Since then, Environmental Performance Assessment (EPA) has become more important to construction contractors. Since EPA is a new concept for the construction industry in

Hong Kong and there has not been a commonly accepted standard assessment tool for measuring environmental performance, an attempt is made to identify such tool.

There have been a number of methods reported in the literature. Tam *et al* [1, 2] reported a method of estimating the relative importance index (*RII*) of all responses for all criteria, of which the higher the *RII*, the more important the criterion. The results obtained by using this method were consistent with other information sources obtained by conducting interviews with various organizations in the construction industry. However, the method did not show the most dominant criterion and the *RII*s of most surveyed criteria were quite close, i.e. the most dominant criterion was not clearly identified.

Thus, the aims of this paper are:

- To review the criteria used in EPA in the construction industry developed by Tam *et al* [1, 2];
- To propose a new power spectral method to effectively study construction management data by identifying the most important and dominant criterion in a set of surveyed criteria in EPA; and
- To compare the method of estimating *RII* values of the criteria with the proposed power spectral method and to show the effectiveness of the power spectral method.

2. ENVIRONMENTAL PERFORMANCE ASSESSMENT (EPA)

EPA is a process of measuring and analysing factors which are recognized as having direct and indirect impacts on the environment [12]. EPA helps to improve the environmental performance by providing information about achievement in environmental policies, objectives, targets, actions, and responsibilities in organizations. The EPA system can also measure, analyse and assess organizational environmental performance [13, 14]. Moreover, reports generated by using the EPA can identify ways to prevent pollution, which assists the identification and establishment of an environmental program in an organization. EPA can also provide continuous information on the implementation and operation of the program [12].

To apply the EPA system, relevant criteria are required which can be used to assess environmental performance of organizations. A set of criteria developed by Tam *et al.* [1, 2], are employed for this research under three main categories: Environmental Management Criteria (EMC), Environmental Operational Criteria (EOC) and Performance Measurement Criteria (PMC). A summary of all criteria is shown in Table 1a & b.

Table 1a: Criteria for the EPA under categories EMC, EOC and PMC [1, 2]

Categories	Criteria	Covered area
EMC	1	*Top management involvement* that sets the strategic direction and beliefs to provide resources in implementing environmental management from top managerial staff.
	2	*Middle management* involvement that sets the management culture on operational management and resources allocating.
	3	*Frontline staff* involvement that sets the blue-collar culture focusing on production or services.
	4	*Management co-operation* between different layers of management.
	5	*Workability and achievement of environmental policies* is to regular review the compliance of company environmental policy, objectives and targets over the construction period.
	6	*Training for top management* to increase the awareness on environmental issues from top managerial staff.
	7	*Training for middle management* to increase the awareness on environmental issues from middle level staff.
	8	*Training for frontline staff* to increase the awareness on environmental issues from frontline staff.
	9	*Pre-auditing planning* to provide a good preparation before auditing activities.
	10	*Frequency in auditing activities* to assess the fulfillment on implementing auditing activities on environmental issues.
	11	*Post-auditing corrective actions* to truly reflect both management staff and employees involvements in environmental management.
EOC	12	*Monitor of energy usage* to assess the reduction and control of the energy.
	13	*Quality of maintenance* to ensure the equipment provided with suitable maintenance.
	14	*Water sprays for minimizing dust airborne particles* to ensure the air pollutants emitted outside construction site by water sprays.
	15	*Mitigation measures to the generation of polluted air* to ensure the air pollutant emitted outside construction site by other means.
	16	*Time management* to control the generation of noise pollutants at restricted hours and close to adjoining noise sensitive parties.
	17	*Mitigation measures to noise levels* are necessary to control the generation of noise pollutants by other means.
	18	*Monitor of water usage* to control the water consumption in promoting water conservation.
	19	*Water reusing and recycling systems* to promote the water reuse and recycling system.
	20	*Wastewater treatment* to control the cleanliness for wastewater outside construction site.
	21	*Purchasing management* to control the right quantity of materials purchased with the most limited waste.
	22	*Waste reuse and recycling* to promote the waste reuse and recycling system.
	23	*Green construction technology* to promote the adoption on green construction technology, such as prefabrication.
	24	*Chemical waste treatment* to control the adequate procedures in preparing chemical waste.

Table 1b: Criteria for the EPA under categories EMC, EOC and PMC [1, 2]

Categories	Criteria	Covered area
PMC	25	*Non-compliance records of inspection* received to indicator the serious situation happened.
	26	*Complaints/warnings* received to indicate the minor situation happened.
	27	*Fines and penalties* received to indicate the seriousness of the non-complaisance records.
	28	*Non-conformance reports* received in auditing indicating the serious problem occurred.
	29	*Reports of marginal cases put under observations* received in auditing in indicating the minor situation occurred.
	30	*Energy consumption* to achieve reduction of energy used.
	31	*Timber consumption* to achieve reduction of timber used.
	32	*Paper consumption* to achieve reduction of paper used.
	33	*Water consumption* to achieve reduction of water used.

3. RESEARCH SURVEY

To unveil the importance of the developed criteria in the categories of EMC, EOC and PMC in the last section, questionnaires and interviews were conducted. Thirty-three criteria in Table 1a & b are under investigation in the survey. Importance levels from "1" to "7" of each criterion are asked on the questionnaire.

Questionnaires were sent to 377 practitioners on governmental departments, building developers, construction consultants, building contractors and sub-contractors in Hong Kong. The companies involved in the survey were chosen from the member list of the Hong Kong Construction Association, the list of building contractors approved by the Government of Hong Kong Special Administrative Region [15], the approved building contractors' list of the Hong Kong Housing Authority [16] and related governmental websites.

In return, 114 questionnaires were completed giving a response rate of 30.24%. However, 2 of them were found invalid, making the total of 112 valid responses for the study.

The questionnaire respondents can be classified into five main categories according to the nature and scale of their business:

- G1 − Governmental departments and developers
- G2 − Construction consultants
- G3 − Large-sized building contractors with capital exceeding fifty million Hong Kong dollars[1]
- G4 − Medium to small-sized building contractors with capital not exceeding fifty million Hong Kong dollars
- G5 − Sub-contractors

Besides, individual interviews were arranged with seven respondents of different business sectors, including one from governmental department, one from building developer, two from environmental consultants, one from large-sized building contractor, one from small-sized building contractor and one from sub-contractor. The

[1] This classification is based on the grouping of Hong Kong Housing Authority's lists of building contractors.

interviews were intended to gather further comments, elaboration and interpretation on the results obtained from the survey results.

4. RESEARCH METHODOLOGY

This section outlines a new method: power spectrum, which can be used to assess the EPA criteria. From that, the most important criterion can be identified which significantly improves environmental performance of organisations. A number of simulation programs have been written using a MATLAB package. This effectively improves ways which organizations can use to prevent damage to the environment. A brief description of the relative importance index (*RII*) [1, 2] method is also given. Performance of the *RII* and power spectral methods is discussed.

4.1 The *RII* method

The *RII* method provides a benchmark to assess the importance of EPA criteria. To determine the relative important of EPA criteria, scores were aggregated and transformed to relative importance indices based on the following formula:

$$RII = \sum \frac{w}{NA}, \qquad (1)$$

where:

w is the weighting given to each factor by the respondent, ranging from 1 to 7 with '1' corresponds to the least important and '7' to the most important;
A is the highest weight; in this study it is 7; and
N is the total number of samples.

As a result, *RII* values are always positive and less than unity. It is clear that the *RII* method uses the relative mean of all responses to determine the *RII* value. Although consistent results have been reported [1, 2], it is believed that the *RII* method cannot completely identify the most-dominant criterion because of the locality characteristic of the mean which will be discussed in more detail in Section 5.1.

4.2 The power spectrum

It is necessary to estimate its total power or energy, which is given by a power spectrum $P(f)$, as shown in Eq. (2).

$$P(f) = |X(f)|^2, \qquad (2)$$

where $X(f)$ is the Fourier transform of the input signal.

It is evident that the power spectrum is proportional to the square magnitude of the input signal. Fourier transform as expected because the signal energy is directly related to its squared magnitude. It is important to stress that energy plays an important role in determining data characteristics, i.e. periodic, aperiodic or chaotic, detecting transitions from one state to another, i.e. a transition from periodicity to chaos or from periodicity to transient, and working out the energy weighting at different frequencies [17] which can be achieved by estimating the power spectrum of the input data. In the case of environmental management, the power spectrum is particularly useful as it can be used to reveal the energy distribution of data points obtained from various surveys. For example, consider that a survey consisting of a set of questions which have been distributed to a number of sources to fill out. A person fills out the questions in the survey at any one time, which means that the energy distribution of the person on the various questions in the survey can be estimated using the Fourier transform and the power spectrum under the assumption that the person fills out all of the questions by himself or herself.

5. RESULTS AND ANALYSIS

This section shows how the power spectrum is used to identify the most important and dominant criterion in the surveyed EPA criteria. Detailed comparisons of the *RII* and power spectral methods are also given. By using the power spectrum, it is possible to find effective ways to improve environmental performance of organizations, yielding improvement in their efficiency and productivity.

5.1 Identification of the most-dominant criterion

Normally, for most surveys, people are asked to fill out a number of questions of ranking from 1 to 7, with 1 as the weakest and 7 as the strongest. Then, the "mean" of these responses is estimated and the larger the mean, the more important the criterion is. For example, if being asked whether air pollution or water pollution is more important than human health, some weighting will be given to each of these criteria. From that the average mean of each criterion is used to determine whether it is more important to have the air not polluted or water not polluted. The method of calculating the mean of all responses has been reported in various works in the field of environmental management with some success [1, 2]. However, it should be noted that this method only locally considers the effects of responses, not globally, i.e. the mean does not completely describe the distribution value of the responses, if one response's value is very high the rest are very low, then the mean of the criterion is still lower than the highest value.

To remedy the problems in using the *RII* method, the power spectra of the data obtained by conducting the survey given in Table 1a & b are estimated using MATLAB. The peak of each power spectrum is then determined which is then used to identify the most dominant criterion. It should be noted that the poorer spectrum is obtained using Eq. (2) which is square magnitude of the input data's Fourier transform. The power spectra of periodic signals usually consist of a number of harmonic dominant peaks which can be considered as the dominant criteria in a survey. The locations of these peaks reveal the criterion number which helps organizations identify specific dominant criteria. It should also be stressed that even though the most dominant criteria can be identified using the power spectrum. The power spectra of all criteria have been estimated, and it has been observed that they are quite similar except some expected variation in the peak magnitude which represents the non-uniform energy distribution among various EPA criteria. This shows that there must exist the most-dominant criterion which can be used to improve environmental performance of organizations in the industry.

It should be noted that the data obtained in the survey are completely random, and by displaying monotonic characteristics, it can be said that the data can be in the transition to chaos. From that, ways to present pollution to the environment can be effectively implemented. Figure 1 plots the normalized power spectral peaks and normalized *RII* values [1, 2] of the data points obtained in the survey. To obtain the normalized values, all *RII* values are divided by the maximum *RII* and all power spectral peaks are divided by the maximum peak yielding the maximum normalized value of unity. From Figure 1, it is difficult to identify the most dominant criterion using the *RII* method as there is not distinctive dominance displayed in their *RII* values, whereas, criterion 10 *frequency of auditing activities* is revealed as the most dominant by using the power spectral method.

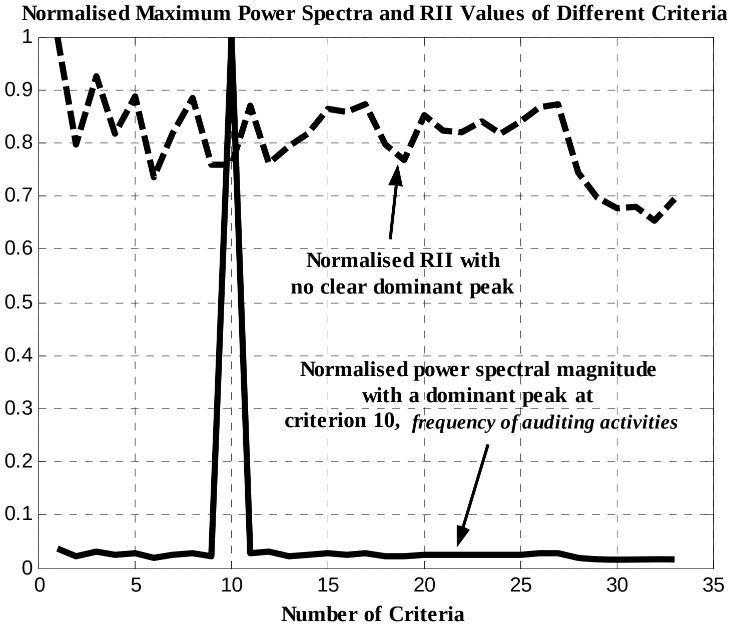

Figure 1: Normalized spectral peaks and *RII* values of 33 criteria given in Table 1a & b plotted on the same graph, from that the dominant peak of using the power spectrum method is clearly revealed, which could not be given by using the RII method.

From Figure 1, using the power spectral method, it is evident that criterion 10, *frequency in auditing activities*, dominantly possesses the strongest power spectral peak and therefore is the most important criterion out of the 33 criteria listed in the survey. The power spectral method applying to the EPA criteria shows that the more frequent the auditing activities being performed, the better the environmental performance of organizations. From Figure 1, for the *RII* method, criterion 1 *top management involvement* was considered by Tam *et al* [1, 2] even though this criterion did not possess clear dominance over the others. In fact, this result is consistent to the result obtained by using the power spectral method because *top management involvement* can be considered as a sub-criterion of *frequency of auditing activities.* The former is usually considered by most organizations as the most important criterion. However, it is *frequent* *top management involvement* practice that truly makes organizations significantly improving their environmental performance. The most crucial condition in this case is the frequency involvement of top management. The only way to achieve frequent *top management involvement* is to exercise *frequent auditing activities* which effectively makes top management of organizations more frequently involved in preparing and improving organizations' environmental performance.

In addition, according to environmental consultants during the interview discussion in this survey, auditing documents and control processes should be monitored daily to achieve the highest environmental standards. One of the interviewed project managers also argued that if organizations need to achieve satisfactory standards in auditing activities, it is necessary to be well-prepared the relevant pre-auditing documentations. At the same time, this also implies that the construction activities are working under satisfactory environmental standards both in the managerial and operational levels. It is clear that to maintain satisfactory standards, organizations experience the "pressure" of wanting to perform well during the audition period, resulting in more frequency involvement of top management to other levels of management from managers to front-line workers. This no doubt significantly improves the environmental performance of the organization under audition. Further, it is evident that, after a successful audition, the organization is left with confident and ready to perform well in the next audition which will happen shortly during the near future. Thus, higher performance can be achieved through this continuous improvement process. Clearly, this process not only greatly improves the environmental performance of the company but also its throughput, efficiency, productivity, product quality and customer satisfaction. It should be noted that all of the above processes require a substantial amount of investment which can be covered by the end results of much higher productivity and efficiency than before the audition.

Along with the most dominant criterion, other less dominant criteria also guide the company in the right direction. However, its performance is strongly dependent on the most dominant criterion of frequency of auditing. It should be noted that this criterion was not identified as the most dominant by using the RII method, which give a group of criteria which could be equivalently considered as dominant.

6. CONCLUSIONS

This paper studied the EPA criteria using new methods of employing the power spectrum to identify the most-dominant criterion. It has been shown that *frequency of auditing activities* is the most dominant criterion because of its wide and effective impacts to other sectors in an environmental organization such as improving support of top management to other levels to ensure that the organization performs well during the audition period. By having this criterion applied to organizations, it is possible to significantly improve their environmental performance as the main purpose, but also, their productivity, efficiency and customer satisfaction. The power spectrum which have been widely used in the field of signal processing have been shown to be useful in analyzing surveyed data in the field of environmental management.

REFERENCES

1. Tam WYV Tam CM Tsui WS Ho CM, *Environmental indicators for environmental performance assessment in construction*, in *Journal of Building and Construction Management (in press)*. 2006.

2. Tam WYV Tam CM Zeng SX Chan KK Environmental performance measurement indicators in construction. *Building and Environment.* 2005;**41**(2): 164-173.

3. Bossink B Brouwers H Construction waste: quantification and source evaluation. *Journal of Construction Engineering and Management.* 1996;**122**(1): 56-60.

4. Brown L Flavin C Kane H Vital signs 1996: The trends that are shaping our future. New York: Norton Co and Worldwatch Institute, 1996.

5. Morledge R Jackson F Reducing environmental pollution caused by construction plant. *Environmental Management and Health.* 2001;**12**(2): 191-206.

6. Polster B Peuportier B Sommereux I Pedregal P Gobin C Durand E Evaluation of the environmental quality of buildings towards a more environmentally conscious design. *Solar Energy.* 1996;**57**(3): 219-230.

7. Clements R Complete guide to ISO 14000. Englewood Cliffs, N. J.: Prentice Halh, 1996.

8. Hill R Bowen P Sustainable construction: principles and a framework for attainment. *Construction Management and Economics.* 1997;**15**(3): 223-239.

9. Ofori G The environment: the fourth construction project objective. *Construction Management and Economics.* 1992;**10**(5): 369-395.

10. Poon C Management and Recycling of Demolition Waste in Hong Kong. *Waste Management & Research.* 1997;**15**: 561-572.

11. Environmental Protection Department Hong Kong Environment 2001. Hong Kong Government, 2001.

12. Wathey D O'Reilly M ISO 14031: a practical guide to developing environmental performance indicators for your business. London: Stationery Office, 2000.

13. Kuhre ISO 14031--environmental performance evaluation (EPE): practice tools and techniques for conducting an environmental performance evaluation. Upper Saddle River, N.J.: Prentice Hall PTR, 1998.

14. Ren X Developing of environmental performance indicators for textile process and product. *Journal of Cleaner Production.* 2000;**8**(6): 473-481.

15. Hong Kong Housing Authority http://www.info.gov.hk/hd/eng/ha/publications.htm

16. Hong Kong Construction Association http://ww.hkca.com.hk/members

17. Lathi BP Modern Digital and Analog Communication Systems. NewYork: Oxford University Press, 1998.