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JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT
ISSN 1392-3730 print/ISSN 1822-3605 online
2012 Volume 18(1): 14–23
doi.org/10.3846/13923730.2011.619326

REVIEW ON WASTE MANAGEMENT SYSTEMS IN THE HONG KONG CONSTRUCTION INDUSTRY: USE OF SPECTRAL AND BISPECTRAL METHODS

Vivian W. Y. Tam[1], **Khoa N. Le**[2], **S. X. Zeng**[3]
[1, 2]*School of Engineering, University of Western Sydney, Locked Bag 1797, Penrith South DC, NSW 1797, Australia*
[3]*Antai School of Management, Shanghai Jiaotong University, Shanghai 200052, China*
E-mail: [1]vivianwytam@gmail.com (corresponding author)

Received 14 Sept. 2010; accepted 08 Dec. 2010

Abstract. The Hong Kong government has implemented various measures to reduce waste, including a waste disposal ordinance, a green manager scheme, a waste reduction framework plan, a pilot concrete recycling plant, waste management systems and a landfill charging scheme. However, there are difficulties in implementing the waste management systems for contractors. This paper examines the existing implementation of waste management systems in the Hong Kong construction industry. Major sources of construction waste, awareness to install environment-friendly activities, benefits, difficulties and recommendations in the implementation of waste management systems are discussed. Questionnaire survey and structured interviews are conducted. Power spectra and bispectra of the survey data are introduced to assess the implementation of the existing waste management systems. It is found that formwork and temporary hoardings are the major sources of construction waste. Improving environmental performance is ranked as the least project scope for construction projects. "Propose methods for reducing waste" is the major benefit gained. However, "Lack of well-known effective waste management methods" is the major difficulty encountered by organisations. "Use of metal formwork", "Use of prefabricated building components" and "Use of non-timber hoarding" are the recommended methods to improve the existing implementation of waste management systems.

Keywords: waste management system, construction and demolition waste, power spectrum, bispectral, construction, Hong Kong.

1. Introduction

Waste is defined as any material by-product of human and industrial activity that has no residual value (Serpell, Alarcón 1998; Ortiz *et al.* 2010). Construction and demolition waste is a mixture of surplus materials arising from site clearance, excavation, construction, refurbishment, renovation, demolition and road work (Environmental Protection Department 2009). Over 80% of construction waste is inert, which include debris, rubble, earth and concrete, are suitable for site formation and land reclamation (Environmental Protection Department 2009). The remaining non-inert substances in construction waste, which include bamboo, timber, vegetation, packaging waste and other organic materials, are not suitable for site formation or land reclamation and are disposed of at landfills. Overall construction waste received at landfills includes construction waste from construction sites and waste concrete that is generated from concrete batching plants and cement plaster / mortar manufacturing plants not set up inside construction sites.

From the statistical data of Environmental Protection Department (2009), about 23% of the waste is generated from construction and demolition activities. About 7% (about 3.27 million tones per year) of the generated construction and demolition waste is sent to landfill; majority of the construction and demolition waste (about 93%) is sent to public fill reception facilities recovered for recycling of which about 49% are recovered. The major recovered recyclable materials are plastics (about 38%), paper (about 32%), ferrous metals (about 23%), non-ferrous metals (about 3%) and others (about 3%).

Major causes of materials wastage on the main construction materials, including stone slabs, concrete, mortar, roof tiles, reinforcement, formwork and brick / block are investigated (Shen *et al.* 2002) (see Table 1). It is most commonly caused by (Cheung *et al.* 1993; Shen *et al.* 2002): i) cutting; ii) over ordering; iii) damage during transportation; iv) lost during installation; v) poor workmanship; and vi) change of design.

A comprehensive construction waste management is there urgently required on every construction site. After identifying the causes of construction waste, it is important to find ways to minimize them. As the promotion of environmental management and sustainable development is popular in recent years, there is a growing awareness of environmental issues and potential problems from environment deterioration. Generally speaking, construction is not an environment-friendly activity. The previous researchers provided comprehensive reviews on the effects of construction activities on the environment (Construction Industry Research and Information Association

Table 1. Causes of material wastage (Shen *et al.* 2002)

Application of construction material	Causes	Specification
Stone slabs	Cutting	Lack of tuning between sizes of different products; imperfections of the product; waste-causing choices in design; lack of knowledge about building during the design stage
	Shape	Imperfections of products; choices made in design about specifications of the product; method of transportation
	Quality	Choice of a low-quality stone slab in design; lack of influence of contractors and lack of knowledge about building during the design stage
	Order too much	Lack of possibilities to order small quantities
	Storage and handling on construction site	Unpacked supply
	Cracking during transportation	Unpacked supply
Concrete	Ordering too much	Required quantity of products unknown due to imperfect planning
	Loss during transportation	Required quantity of products unknown due to imperfect planning
	Scraping off	Method to lay the foundations of a building
Mortar	Scraping out	Negligent practice
	Mortar in the tub	Negligent practice
	Atmospheric influence	Negligent practice
	Specifications of the mortar	Short processing time
	Messing	Negligent practice; quantities of supply too high
Roof tiles	Sawing consequent from the design of the roof	Attention not paid to sizes of the products used in design; designer not familiar with possibilities of different products; information about that will be used late; types and sizes of the different products do not fit
	Cracking during transportation	Negligent handling by the supplier
Reinforcement	Cutting	Use of steel bars of sizes that do not fit
Formwork	Cutting	Use of timber boards of sizes that do not fit
Brick / Block	Cutting	Use of sizes that do not fit
	Damaged during transportation	Unpacked supply

1993; Hill, Bowen 1997; Begum *et al.* 2007, 2009; Rodríguez *et al.* 2007; Tam 2008a; V. W. Y. Tam, C. M. Tam 2008; McMahon *et al.* 2009; Tam *et al.* 2009; Cheng *et al.* 2010). These effects include land use and land deterioration, resource depletion, waste generation and various forms of pollution (United Nations Centre for Human Settlements 1990, 1993; Lenssen, Roodman 1995; Worldwatch Institute 1995; Brown *et al.* 1996; V. W. Y. Tam, C. M. Tam 2006a, b; Tam *et al.* 2006a; Begum *et al.* 2009).

The Hong Kong government has employed various waste controlling measures in the past few years, including launching a waste disposal ordinance, a green manager scheme, drafting a waste reduction framework plan, commissioning a pilot concrete recycling plant, stipulating the implementation of waste management systems, and promoting a public landfill charging scheme (Environmental Protection Department 2009).

It is compulsory that every construction company should enact construction waste management systems tailored to its particular mode of business so that every personnel from the management to the operational level can head for the same goal of reducing construction waste. However, there are difficulties affecting sustainable implementation of the waste management system in the Hong Kong construction industry.

This paper focuses on investigating construction and demolition waste problems, examining the existing waste management approaches in the construction industry; investigating benefits and difficulties of the existing waste management systems using power spectral and bispectral methods; and recommending methods to improve sustainability of waste management systems.

2. Research methodologies

To examine the implementation of waste management systems in the Hong Kong construction industry, a questionnaire survey was conducted. The questionnaire survey is divided into several sections, including major sources of construction waste, awareness to installation of environment-friendly activities, benefits in implementing waste management systems, difficulties in implementing waste management systems, and recommended methods for improvement of waste management system implementations. A seven-point scale was attached to each question in each section of the questionnaire survey. The survey was randomly sent to 500 parties from the list of contractors, consultants, developers, government departments, and environment professional associations available on the related association websites. The total number of representatives available is more than thousands. 327 had been received with a response rate of about 65.4%. However, two of the questionnaires were not properly completed and only 325 questionnaires were valid.

This survey was conducted in 2007 and the results were analysed using the relative importance index method and have been published in 2008 (Tam 2008b). This paper aims to use power spectral and bispectral methods to analyse and hence gaining insight to the survey. This can provide an in-depth understanding on the data for the industry about the implementation of waste management systems. Spectral methods do not require any special information which is suitable for the seven-point scale survey data.

Power spectra of the data are used to analyse the survey results in this paper. Power spectra of a dataset are usually employed to show the data's energy distribution which can be used to identify dominant data points and data characteristics. It should be noted that the power spectra are complex numbers which are uniquely described by their magnitude and phase. Thus, it is clear that there are two ways of representing the data: in the time domain and in the frequency domain. The transformation from time domain to frequency domain is achieved by using the operator $e^{j\omega t}$, which can be given in Eq. (1) as:

$$e^{j\omega t} = \cos(\omega t) + j\sin(\omega t). \quad (1)$$

Frequency is normally defined as the number of repetitions over time and the concept of "frequency domain" is believed to be new in the field of construction management. Frequency is inversely proportional to time, which means the larger the time, the smaller the frequency and vice versa. Using the concept of frequency and time, it can be said that data which have a long time span have densely-concentrated spectra over a short frequency range and vice versa. The magnitude of the frequency components which are displayed over a frequency range or spectrum is defined as proportional to the signal energy. Signals which are continuous and periodic in time have densely concentrated energy spectra.

The power spectrum $P(f)$ of a data set $x(t)$ is given in Eq. (2) as:

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

where $X(f)$ is Fourier transform of the data or input signal. It is evident that the power spectrum is proportional to the square magnitude of the input signal's 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 (Lathi 1998) which can be achieved by estimating the power spectrum of the input data. In the case of studying sample results of tests in construction material and management, the power spectrum is particularly useful as it can reveal the energy distribution of samples in each test. From that, the significance of each test can be assessed. In addition, the power spectrum can be used to classify different types of data including periodic, chaotic, transient and noise by interpreting its shapes and frequency range (Le *et al.* 2003). Moreover, as data processing and analyses are increasingly important, this further strengthens the idea of using spectral methods in the field of construction management. It is thus evident that spectral methods which have been successfully employed in the field of signal and image processing can also be employed in the field of construction management. The only drawback of the power spectrum is that its phase information is suppressed which means that two different data sets could have identical power spectra.

To further study the data, a bispectral method is introduced which shows the correlation among the criteria at various "frequencies". The bispectrum has been widely employed in the field of high-order statistics to study data correlation. The bispectrum $B(f_1, f_2)$ of the input signal in 3-D is given by van Milligen *et al.* (1995):

$$B(f_1, f_2) = X(f_1)X(f_2)X^*(f_1 + f_2), \quad (3)$$

where the symbol "*" means complex conjugate.

It is clear that the bispectrum is strongly dependent on the Fourier transform of the input signal. From Eq. (3), the term $X^*(f_1 + f_2)$ represents the correlation among various frequency terms in the $(f_1 + f_2)$ plane. To estimate the bispectrum, the mean value of the data is removed to eliminate sudden spikes and pulses in the bispectrum, which could lead to misleading interpretation. In MATLAB, this can be done by using a `detrend(·)` function. The Fourier transforms of the detrended data are then calculated, when there are n criteria for the system, yielding n Fourier transforms. The bispectrum is then calculated for the data matrix of 112×n. The data size will be normally more than 1,000 columns, which is very common in signal processing, substantial computing work is required which makes the bispectrum sometimes hard to estimate and not practical. However, the bispectrum reveals vital information to the understanding of data characteristics and especially correlation among various criteria at different frequencies. Similar to the power spectrum which is used to locate dominant criteria in a construction management survey, the bispectrum gives the phase information, i.e. the correlation among a number of frequencies, which enable detailed studied of correlation among various criteria in the survey. The phase information clearly gives the bispectrum an advantage compared with the power spectrum method. In terms of construction management, if the power spectrum can yield efficient evidence on how to determine the most dominant factor(s), then the bispectrum may not be required. However, if organizations require on how various questions in a survey related to each other, i.e. the responses of some questions may be "predicted" by studying the responses of some specific group of questions, then the bispectrum can be used to reveal this vital information. As a result, the quality of surveys can be significantly improved, yielding an increase of organizational overall performance. The significant advantage of the power spectrum and bispectrum techniques is these methods can clearly identify the most dominant factor(s) and also "coupling" or correlation phase information which can be used to study the correlation among various factors in a survey. This can help improve survey's quality by removing unnecessary criteria and adding more useful criteria into it.

After receiving the questionnaire responses and analysing the collected data using power spectral and bisepctral methods, individual structured interviews were

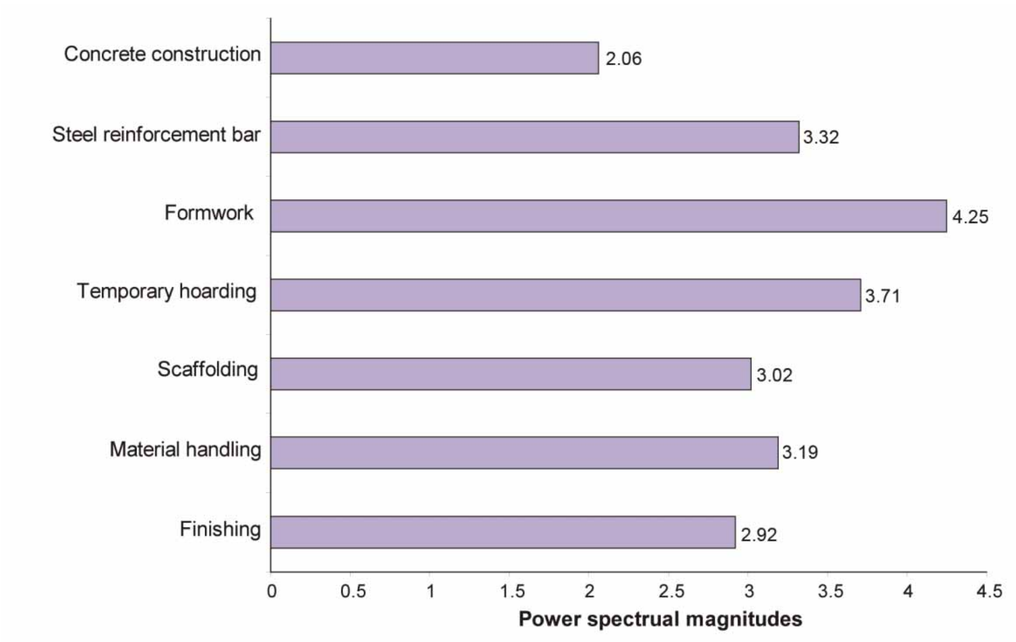

Fig. 1. Major sources of construction waste

arranged with twelve respondents, selected from different business sectors: two government departments, one building developer, two environmental consultants, three registered building contractors, two registered specialized contractors and two members of an environmental professional association. The interviews were intended to gather further comments, to elaboration and to interpret the results obtained from the questionnaire.

3. Results and analysis

3.1. Major sources of construction waste

Fig. 1 shows the survey results of major sources of construction waste. It is found that formwork and temporary hoardings are the major sources of construction waste with power spectral magnitudes of about 4.25 and 3.71 respectively. The interviewed contractor explained that in-situ concreting requires formwork and temporary hoarding to support. Most construction sites are still using timber as formwork and temporary hoarding. This can easily cause wastage from cutting (Cheung *et al.* 1993; Shen *et al.* 2002). The interviewed environmental consultant encouraged contractors to use other materials, such as steel or aluminium rather than timber as formwork or temporary hoarding. Timber can only be used once for formwork or temporary hoarding whereas steel and aluminium can be reused for more than one hundred times. This can significantly reduce the generated waste.

Fig. 2 shows the bispectrum of the major sources of construction waste. The bispectrum of this dataset is seen to possess two main peaks with some transition from one peak to another peak. The peaks seem to have an identical magnitude. Because of the visible transition, the dataset can be used to work out the most dominant factor out of the survey. This can be improved by adding new survey questions to probe further useful information from the correspondents. From that, possible performance improvement can be achieved by concentrating on developing the dominant factor. The dominant factor can also be employed to predict company performance. The bispectrum is therefore can be employed as a useful tool to assess the survey's effectiveness and relevance.

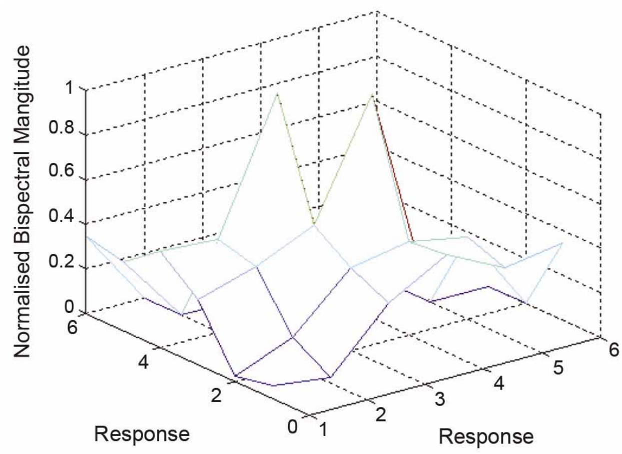

Fig. 2. Bispectrum of major sources of construction waste

3.2. Awareness to install environment-friendly activities

Minimizing cost, shortening time, improving quality, environmental and safety performance are five major project scopes in all construction projects (Tam 2009). Traditionally, minimizing construction cost and shortening construction time are the most important project goals. From the survey results, it is found that improving safety performance is as important as minimizing construction costs (see Fig. 3). An interviewed government officer noted that on-site accident rates have significant roles on waste reduction from the last few years. The

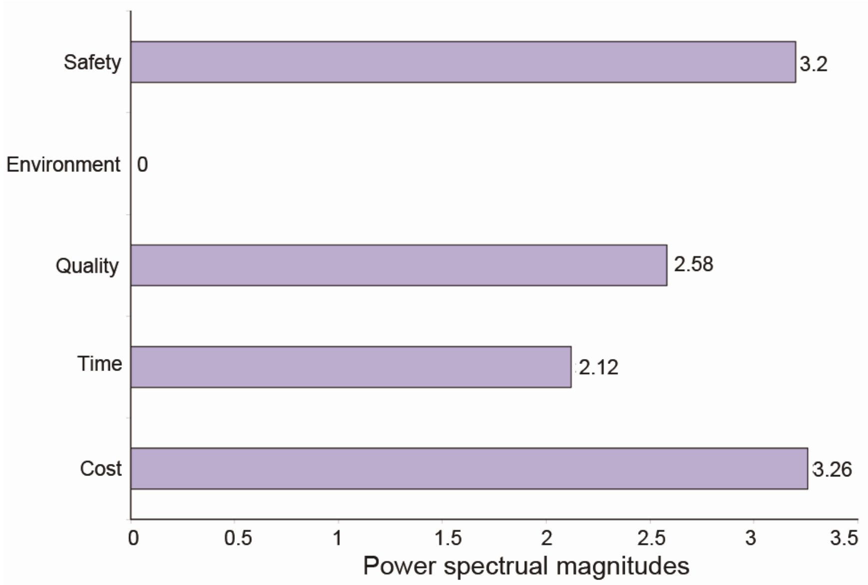

Fig. 3. Importance of project scopes

accident rate has been close to zero in recent times which shows that safety awareness in the industry is becoming popular and accepted. However, installing environment-friendly activities are the least concern from the respondents. An interviewed environment professional association member explained that it has a wrong image that high investment cost is required to improve environmental performance. This can actually achieve long-term cost saving with a long service life cycle.

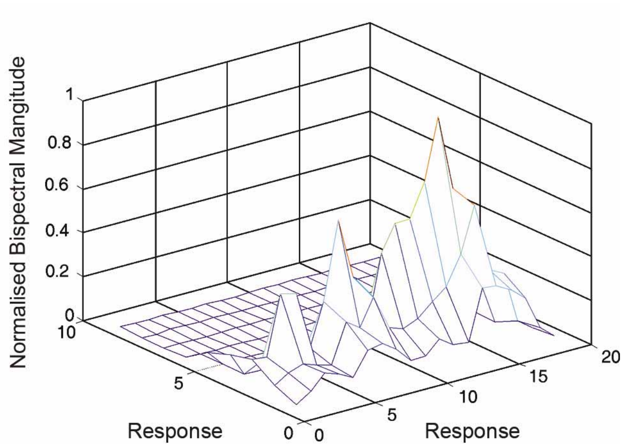

Fig. 4. Bispectrum of importance of project scopes

From Fig. 4, there are about three main peaks and smooth transitions from the top peak to the lowest peak that are clearly visible which suggests chaos in the data. This dataset is hence useful and can be used to find the most dominant peak out of the questions presented in the survey. Comparing with the results given in the figure, additional questions are necessary to further smoothen the bispectrum, yielding a better survey.

3.3. Benefits in implementing waste management systems

The implementation of waste management systems has several benefits such as pollution prevention, better allocation of resources, better regulatory compliance, evaluation of risks and plans for preventing potential problems which can be achieved through the implementation of waste management systems (Tibor 1995; Tam 2008a). Previous studies have identified a number of benefits in the implementation of construction (Kuhre 1998; Jasch 2000; Tam *et al.* 2006b; Begum *et al.* 2009). A list of benefits can be seen in Fig. 5 with the power spectral magnitudes collected from the questionnaire survey.

From the survey results, it is found that "Propose methods for reducing waste" has the highest power spectral magnitude of about 1.69. An interviewed building contractor noted that a detailed procedure on reusing, recycling and reducing different types of construction waste needs to be proposed in the waste management systems, which is also supported by the literature (Tam 2008a, b). This can force them to have an early planning on reducing waste via reuse, recycle and reduction. An interviewed environment consultant suggested that the most common way to reduce waste is (i) recycling concrete waste as recycled aggregate for sub-based concrete applications, (ii) selling wasted steel to recyclers, and (iii) reusing timber formwork as temporary hoardings.

"Propose areas for waste storage" has the lowest power spectral magnitude of about 0.55 from the survey results. An interviewed building developer explained that the ratio of building land size to population is too low in Hong Kong. Buildings are built with at least thirty storeys in height, resulting in insufficient space for waste storage or sorting. Because of the space shortage, construction companies normally just blindly assemble all types of waste together and sent them to landfills which are environmentally unfriendly.

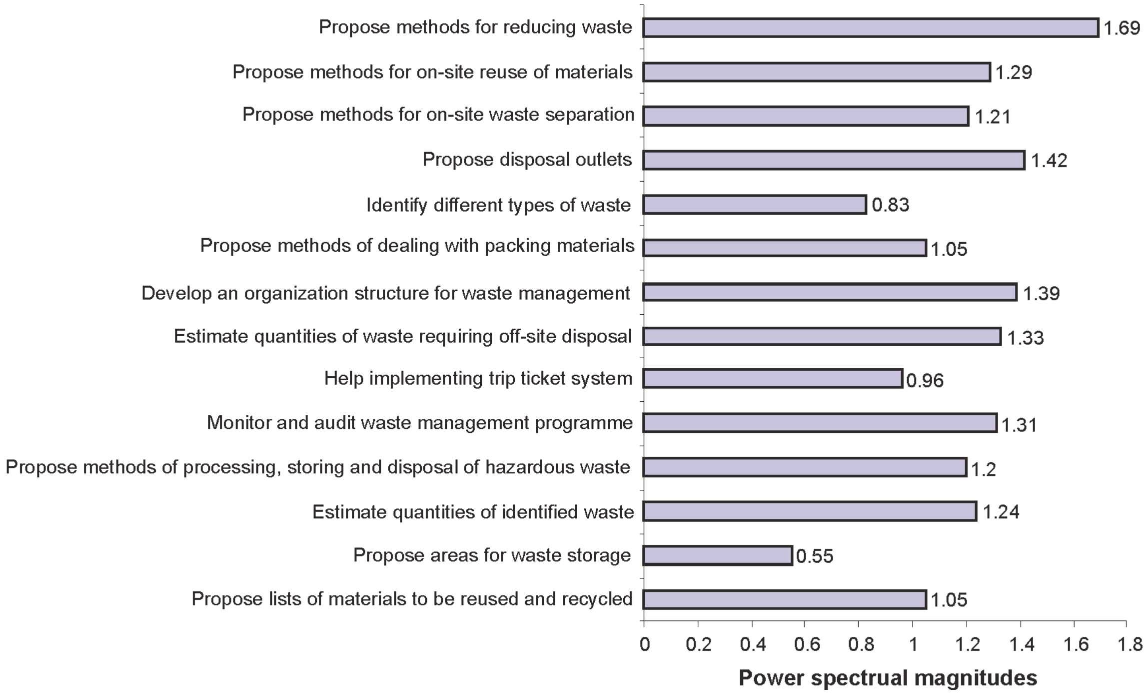

Fig. 5. Benefits in implementing waste management systems

Fig. 6 shows the bispectrum of the benefits gained from the implementation. This dataset is similar to what presented in Fig. 10 from which there exists one dominant peak. It is generally difficult to determine the most dominant factor out of the questions presented in the survey. Additional methods are thus required to find the most dominant factor. However, comparing with the bispectrum in Fig. 2 and Fig. 4, this bispectrum is smoother which represents uniformness in the survey and obtained dataset which is more effective than the previous surveys.

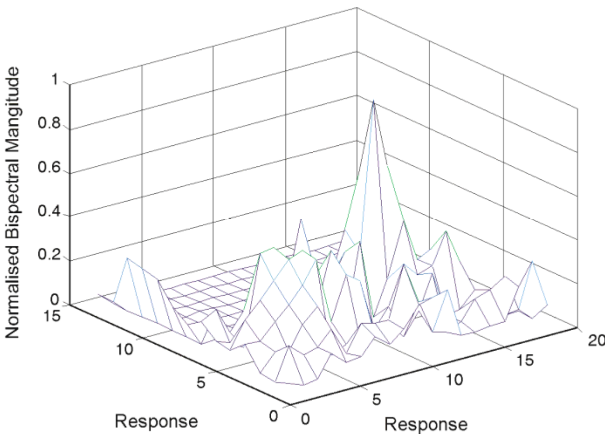

Fig. 6. Bispectrum of benefits in implementing waste management systems

3.4. Difficulties in implementing waste management systems

Although there are many benefits in implementing waste management systems, there are still many construction organizations finding difficulties in implementing these systems. The major reason is high investment cost, such as resource input for training courses (Shen, Tam 2002). Kuhre's study showed that the support of the implementation of the method from top management was crucial at the early stage of the process (Kuhre 1998). Tron's study considered that the lack of relevant empirical experience on the method to support the development of a practical guideline was one of the main concerns for its implementation (Tron 1995). Other major difficulties include lack of resources and expertise, lack of staff involvement and poor co-ordination among the government, industry and businesses (Chan, Li 2001). Based on these previous studies, nine major difficulties are identified and shown in Fig. 7 with the power spectral magnitudes collected from the questionnaire survey.

From the survey results, "Lack of well-known effective waste management methods" has the highest power spectrum magnitude of about 1.63. An interviewed building contractor explained that there is lack of knowledge on waste management methods suitable for particular projects. An interviewed environment consultant encouraged contractors to attend training programmes and seminars at least once a year to enrich their knowledge and understanding on waste management methods. There are a lot of new technologies available to effectively reduce waste generation. For example, small-sized mobile concrete crushers can crush concrete waste on-site and can also be used on the same site for roadwork or sub-bases.

"Low disposal cost" ranked as the least difficulty in implementing waste management systems with the power spectrum magnitude of about 0.91 from the survey results. An interviewed specialized contractor agreed that disposal costs are low compared to costs of implementing waste reduction methods. A landfill charging scheme has recently been implemented in 2005 in Hong Kong, charging HK$125 (or US$16) per tonne. Another interviewed

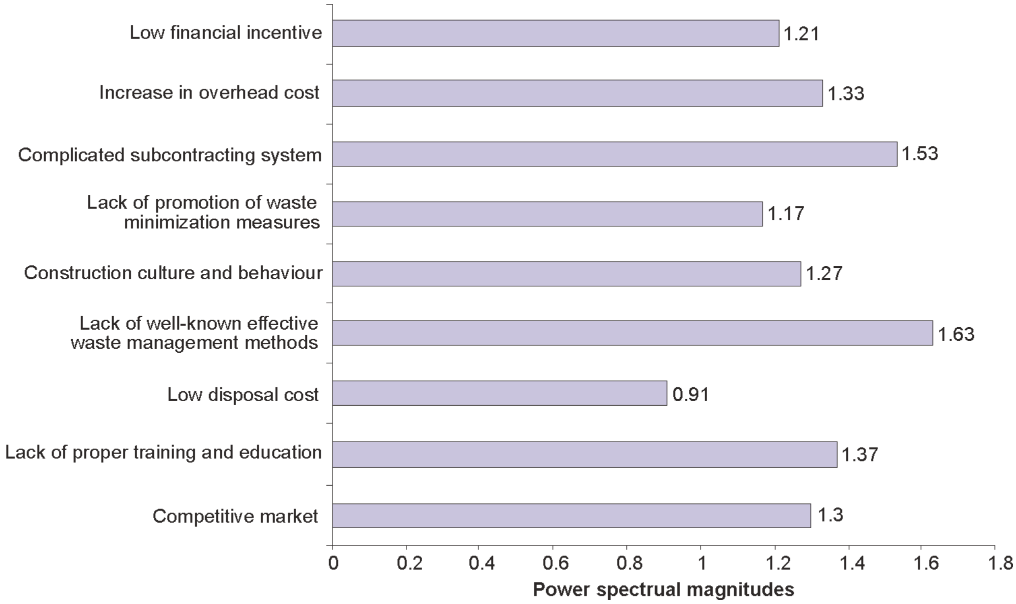

Fig. 7. Difficulties in implementing waste management systems

environment consultant explained that the existing landfill charges did not increase awareness of building contractors on reducing waste. Comparing to other countries, landfill charges are at least double of that in Hong Kong. For example, AU$30–55 (or US$27–50) per tone in Australia, ECU$38 (or US$52) per tone in Denmark and JPY$9,000 (or US$90) per tone in Japan.

Fig. 8 shows the bispectrum of the difficulties in implementing waste management systems. The bispectrum shows several peaks of nearly equal magnitude which suggests that the data are better than those given in Fig. 10. It is also possible to work out the most dominant factor affecting the implementation of waste management systems. The bispectrum represents equally dominant peaks which means that the survey may be congested with similar questions or answers from correspondents and is somewhat similar. Additional work is therefore required to further assess the survey.

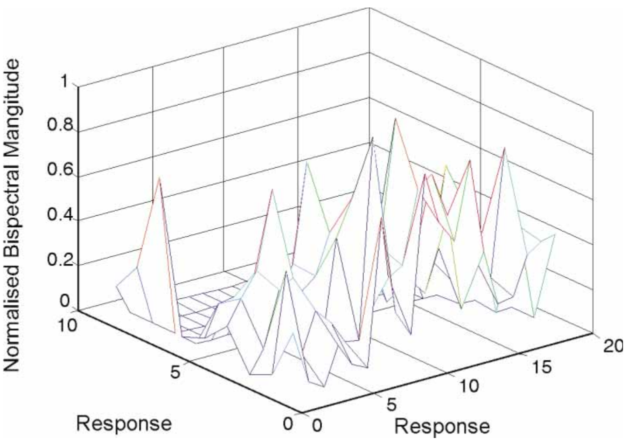

Fig. 8. Bispectrum of difficulties in implementing waste management systems

3.5. Methods to improve waste management systems implementation

There are a number of ways to encourage the implementation of waste management systems for construction activities. For example, applying environment-friendly technologies, on-site sorting and enforcing strict legislations (McDonald, Smithers 1998; Tan *et al.* 1999; Chen *et al.* 2000; Begum *et al.* 2009; Shen *et al.* 2010). Based on the previous findings, fifteen methods in encouraging the adoption of waste management systems are identified. Figure 9 shows the power spectral magnitude collected from the survey for the recommended methods to improve waste management systems implementation.

From the survey results, "Use of metal formwork", "Use of prefabricated building components" and "Use of non-timber hoarding" are ranked as the three most effective measures in implementing waste management systems with the power spectral magnitude of about 2.63, 1.95 and 1.64 respectively. Using metal formwork, prefabricated building components and non-timber hoarding instead of timber formwork, wet trade construction and timber hoarding can significantly reduce waste generation. From the interview discussions, an interviewed developer noted that using 100% prefabrication for construction activities will become a trend in the future, which may be linked to the concept of deconstruction for waste reduction (Tam 2009; Tam *et al.* 2009).

"Implementation of environmental management systems" has the lowest power spectral magnitude for improving the existing implementation of waste management systems of about 1.13 from the survey results. An interviewed building contractor argued that implementing environmental management systems is wasteful and time consuming. In addition, they also noted that too much paperwork is required for the implementation, particular for auditing. An interviewed environment consultant

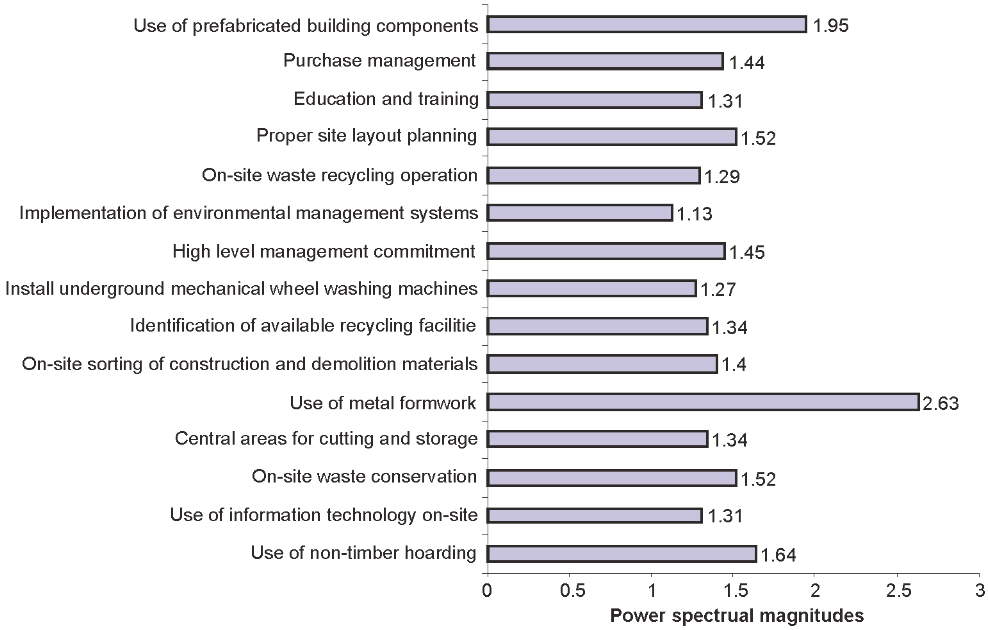

Fig. 9. Methods to encourage the implementation of waste management systems

noted that an initial on-site planning with detailed procedures on waste management before projects start is the most effective approach for waste reduction.

Fig. 10 shows the bispectrum of methods for encouraging the implementation of waste management systems. The bispectrum has one dominant peak in the middle which suggests that the data are periodic. The main reason for this is that respondents could "guess" the questions beforehand and therefore they biased to their pre-responses before the questions were revealed. For this type of data, it is hard to find the most dominant peak among the questions presented in the survey. This bispectrum represents dominant peak and smaller peaks showing the smooth transition from the peak to the smaller peaks in the data. This finding also shows that the survey questions and results are useful.

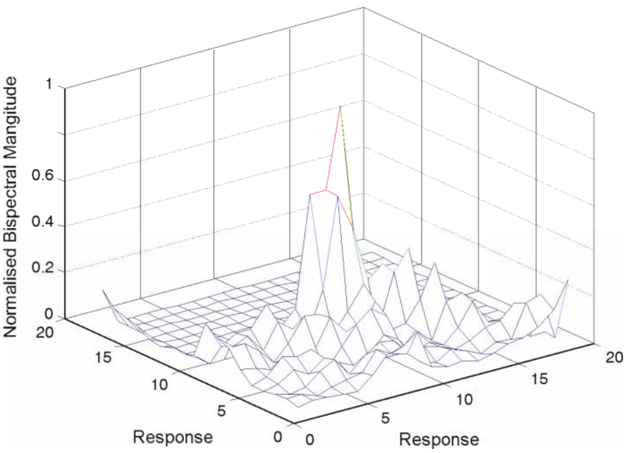

Fig. 10. Bispectrum of methods to encourage the implementation of waste management systems

4. Conclusions

This paper has examined the existing implementation of waste management systems in the Hong Kong construction industry. Questionnaire survey and structured interviews were conducted. The methods of power spectrum and bispectrum were used to analyze the data collected from the survey. Power spectra were used to locate dominant criteria and the bispectrum enabled detailed studied of correlation among various criteria in the survey. It should be noted that the power spectrum and bispectrum, which have been extensively used in signal and image processing, are novel methods which can be used in construction management. By using these novel approaches, an in-depth understanding on survey data can be provided for the industry and for the successful implementation of waste management systems. This can provide a new insight and direction for waste management implementation using superior approaches. From the survey results, it was found that formwork and temporary hoarding are the major sources of construction waste. Improving safety performance is ranking as important as minimizing construction cost for construction projects. However, improving environmental performance is considered as the least project scope in the construction industry. In implementing waste management systems, "Propose methods for reducing waste" is the major benefit gained. However, "Lack of well-known effective waste management methods" is the major difficulty encountered by organisations. "Use of metal formwork", "Use of prefabricated building components" and "Use of non-timber hoarding" are the recommended methods to improve the existing implementation of waste management systems.

Acknowledgement

The author would like to thank Mr. C. K. Chung for conducting the quantitative survey.

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ATLIEKŲ TVARKYMO SISTEMŲ HONKONGO STATYBŲ SEKTORIUJE APŽVALGA: SPEKTRINIO IR BISPEKTRINIO METODŲ TAIKYMAS

V. W. Y. Tam, K. N. Le, S. X. Zeng

Santrauka

Honkongo valdžia įdiegė įvairių priemonių atliekų kiekiui mažinti, įskaitant atliekų šalinimo potvarkį, žaliojo tvarkytojo planą, bendrąjį atliekų mažinimo planą, bandomąją betono perdirbimo gamyklą, atliekų tvarkymo sistemas ir sąvartyno mokesčių planą. Tačiau diegiant atliekų tvarkymo sistemas rangovams kyla sunkumų. Šiame darbe nagrinėjamos Honkongo statybų sektoriuje jau diegiamos atliekų tvarkymo sistemos. Aptariami pagrindiniai statybinių atliekų šaltiniai, žinios apie galimą aplinkai nekenksmingą veiklą, taip pat atliekų tvarkymo sistemų diegimo nauda, sunkumai ir rekomendacijos. Atliekamos anketinės apklausos ir nustatytos struktūros pokalbiai. Pasitelkus per apklausas surinktų duomenų galios spektrus ir bispektrus, įvertinamas esamų atliekų tvarkymo sistemų diegimas. Nustatoma, kad pagrindiniai statybinių atliekų šaltiniai – klojiniai ir laikinos tvoros. Aplinkosaugos charakteristikų gerinimas statybos projektuose laikomas mažiausia projekto dalimi. Pagrindinė gauta nauda – siūlomi atliekų kiekio mažinimo metodai. Tačiau didžiausias organizacijoms kylantis sunkumas – žinomų efektyvių atliekų tvarkymo metodų stoka. Gerinant šiuo metu diegiamas atliekų tvarkymo sistemas, rekomenduojama taikyti tokius metodus: metalinius klojinius, surenkamuosius statinių elementus ir laikinas tvoras ne iš medžio.

Reikšminiai žodžiai: atliekų tvarkymo sistema, statybų ir griovimo atliekos, galios spektras, bispektrinis metodas, statybos, Honkongas.

Vivian W. Y. TAM. Senior Lecturer at School of Engineering, University of Western Sydney, Australia. She received her Ph.D. in sustainable construction from the Department of Building and Construction at City University of Hong Kong in 2005. Her research interests are in the areas of environmental management in construction and sustainable development.

Khoa N. LE. Received his Ph.D. in October 2002 from Monash University, Melbourne, Australia. From April 2003 to June 2009. He was a Lecturer at Griffith University, Gold Coast campus, Griffith School of Engineering. From January to July 2008, he was a visiting professor at Intelligence Signal Processing Laboratory, Korea University, Seoul, Korea. From January 2009 to February 2009, he was a visiting professor at the Wireless Communication Centre, University Technology Malaysia, Johor Bahru, Malaysia. He is currently a Senior Lecturer at School of Engineering, College of Health and Science, Kingswood, University of Western Sydney. His research interests are in wireless communications with applications to structural problems, image processing and wavelet theory. Dr. Le is the Editor in Chief of International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC). He has also been on the Editorial Board of International Research Magazine of Computer Science and other wireless communications journals.

S. X. ZENG. He works in the Antai School of Economics & Management, Shanghai Jiaotong University, China. He received his PhD degree in management from Harbin Institute of Technology, China. As a research fellow, he had worked at City University of Hong Kong. As a researcher in technology management and related fields, he has managed a large number of research projects, and has published more than 120 journal and conference papers, books, and reports on technology management, project management and environmental economics and management. He has successfully supervised a number of PhD and MSc students. Currently he is the Head of Department of Management Science and Director of Institute of System Engineering at Shanghai Jiaotong University.