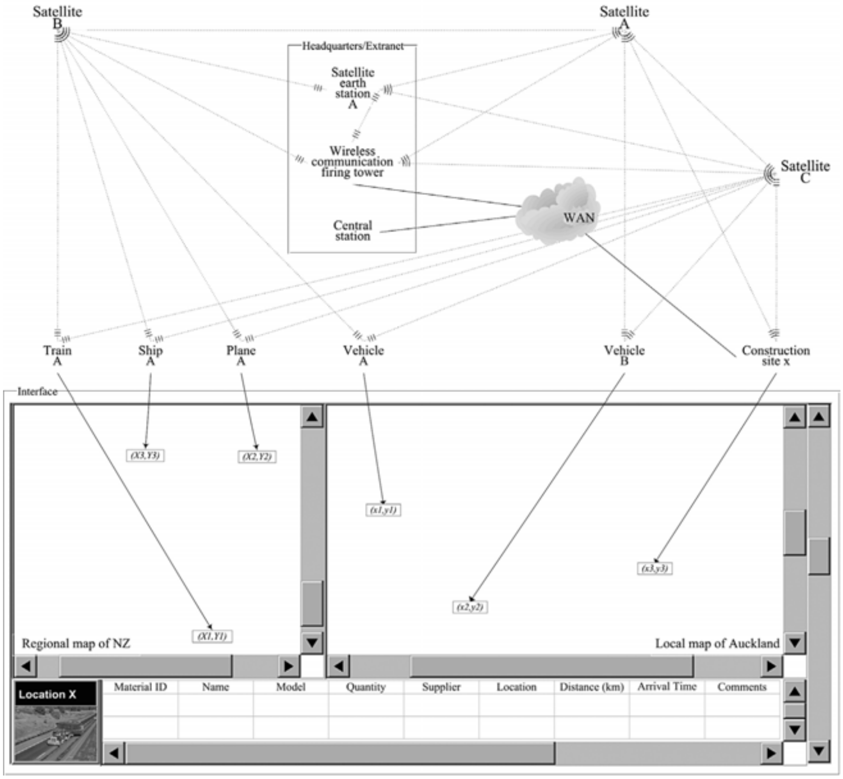


Figure 4.9 A conceptual model of GPS/GIS integrated M&E management system.

Pocket PC, while the GIS software is ArcGIS series from ESRI (Environmental Systems Research Institute, of Redlands, California, USA), which is an integrated collection of GIS software products for building a complete GIS for organizations, including Desktop GIS (ArcReader, ArcView, ArcEditor, ArcInfo, and ArcGIS Desktop Extensions), Server GIS (ArcIMS, ArcGIS Server, ArcSDE, and GIS Portal Toolkit), Embedded GIS (ArcGIS Engine), and Mobile GIS (ArcPad, and Mobile ArcGIS Desktop Systems) (ESRI 2004); and the GPS software is GeoExplorer series from Trimble, which is an integrated collection of GIS-oriented GPS software products for advanced GPS/GIS data collection and mobile GIS tools, including Office Software (GPS Pathfinder Office and Trimble GPS Analyst extension for ArcGIS), and Field Software (TerraSync, GPScorrect for ESRI ArcPad, and GPS Pathfinder Tools Software Development Kit [SDK]) (Trimble 2004). The hardware requirements include enterprise-level computer server for control at central station, distributed computer desktop for operations on construction sites, and mobile laptop, Pocket PC, and handhelds for communications on the road. For

Table 4.13 An example of GPS/GIS integrated M&E management system application

Hardware
Dell® Precision™ WS 370/670 (desktop)/ M60 (mobile) workstation
Dell® PowerEdge™ 6600 (enterprise-level) server
Trimble® GeoExplorer® series handhelds
PSC QuickScan® 5385 scanner with keyboard wedge type of decoder
Handbook of bar-code labels for construction M&E (internal)
Software
Microsoft® Windows® Server 2003 SE
Microsoft® Windows® NT/2000/XP/CE
Microsoft® Pocket PC
Microsoft® Office® XP
Loftware® Label Manager
ESRI® ArcGIS® series
Trimble® GeoExplorer® series

example, Trimble GeoExplorer series handhelds, which are the most advanced GPS/GIS data collection and mobile GIS tools available, combining a Trimble GPS receiver with a handheld computer running Microsoft Windows Mobile 2003 software for Pocket PCs (Trimble 2004), was chosen to support the operation of the GPS/GIS data collection, including GeoXT, GeoXM, Beacon-on-a-Belt, External Patch Antenna, etc., whilst Dell PowerEdge enterprise-level server was chosen to operate the GPS/GIS integrated central construction M&E management system at central station, and Dell Precision series of desktop/laptop workstations were chosen to operate the GPS/GIS integrated on-site construction M&E management system on construction sites. Table 4.13 gives an example of the hardware and software components for the GPS/GIS integrated construction M&E management system application.

Provided the development period of the proposed GPS/GIS integrated construction M&E management system is not acceptable to an urgent need from a construction sector, commercial solutions such as the Trimble construction solutions (Trimble 2004) can be used.

4.7.4 A pilot study

4.7.4.1 The problem

C&D waste has been identified as a priority waste in the New Zealand Waste Strategy because of its quantity and complexity, which sets a target of 50% waste reduction in waste being disposed of to landfills by 2008, and requires local authorities to put in place programmes for monitoring C&D waste quantities (MFE 2004). Under this circumstance, a Hong Kong-based construction company had an ongoing project at Auckland, New Zealand (refer to Figure 4.9), and the managers at the headquarters in Hong Kong wanted to deploy all construction M&E by using the GPS/GIS integrated construction project management system, and implement the crew IRP on the construction site at Auckland to fulfill the company's environmental promise in minimizing construction waste.

Regarding the construction M&E required in this project, most of them are supplied and transported from Australia and China, except a limited quantity of M&E which are ordered from local suppliers in New Zealand. In order to carry out the construction schedule on time and reduce waste, site managers at Auckland had to try hard to pay attention to their M&E management, and struggled with adverse atmospheric conditions in New Zealand. As a result, they asked the headquarters to provide much accurate information regarding the arrival time of construction M&E so as to deal with limitations of M&E storage on site and the varied weather conditions there.

4.7.4.2 Requirements specification

As managers from both the headquarters and construction site need dynamic accurate location information of M&E to push on their jobs effectively, the demand for immediate response time and tight command and control necessitates the GPS/GIS integrated solution to enable real-time interactive communications for dispatch and navigation, and server-based cargo tracking and messaging and others. A construction fleet management process based on the GPS/GIS integrated construction M&E management system (refer to Figure 4.9) should have the following major positioning-related requirements from both the headquarters at Hong Kong and the construction site at Auckland:

- Efficient dispatch and supervisory central control of cargoes among the construction site and the M&E suppliers from China, Australia, New Zealand, and other places at the headquarters side, which means

    1. to correctly arrange the departure time and routes of each cargo from suppliers,
    2. to accurately define the arrival time of each cargo at the construction site,
    3. to actively track the dynamic position of each transportation,
    4. to timely monitor and control the process of each transportation from departure to arrival, and
    5. to dynamically record any delay due to the transportation by suppliers for further claiming indemnity, etc.

- Efficient dispatch and supervisory on-site control of cargoes on the road and M&E on site at the construction-site side, which means

    1. to dynamically check the location of each cargo on the road to the construction site,
    2. to timely communicate with the headquarters about each transportation,

3 to accurately record the arrival time of each cargo on site,
4 to accurately record the details of each cargo arrived on site, and
5 to accurately record the details of each material or equipment received by each crew, etc.

4.7.4.3 Solutions

The headquarters at Hong Kong chose the outlined commercial solutions from Microsoft, Loftware, ESRI, and Trimble (refer to Table 4.13) to provide integrated GPS/GIS capabilities for managers on both sides for dynamic construction M&E management. There are two phases in the deployment of the application. In Phase I, proposed GPS/GIS devices including software system and hardware system are planted into the currently used construction M&E management system, which is integrated as a M&E subsystem with an enterprise-wide construction project management system. Detailed GPS coordinate information, including extensive map as well as latitude, longitude, date, and time, could be displayed in the system. The enhanced system was modified to interface with the headquarters' existing construction project management system and construction engineering system. In Phase II, Trimble external patch antenna (EPA) is adhered to each cargo on the road to the construction site as a kind of vehicle location device (VLD). The Trimble EPA is specially designed for seamless integration with Trimble GeoExplorer series handhelds and the WAN infrastructure, and is ideal for use in all environments where a high yield of positions is required (Trimble 2004). By automatically positioning each transportation, real-time information of each cargo will be accessible for both central and on-site construction M&E management systems.

4.7.4.4 Results

Managers in both the headquarters at Hong Kong and the construction site at Auckland were satisfied with the novel application of integrated GPS/GIS technology in construction management, in which the specified values are all actually achieved, such as the reduction of construction waste and the improvement of construction efficiency. Table 4.14 provides a comparison of the non-integrated system versus the GPS/GIS integrated system for the construction M&E management solution. According to the comparison, the GPS/GIS integrated solution can improve the construction efficiency through increasing the effective working hours of construction equipment and reducing construction duration and the cost of workforce, as well as reduce the generation of construction waste. Due to the initial investment in the hardware and software systems, original cost increased compared with the former crew IRP-based bar-code system; however, this can be overcome during further utilization of the new system.

Table 4.14 Comparison of non-integrated system versus the GPS/GIS integrated system

Parameter	*Non-integrated system*	*Integrated system*	*Variation (%)*	*Compliant*
Hardware cost	$2,500	$8,000	↑220	No
Software cost	$1,200	$6,000	↑400	No
Equipments utility	3,100 hours	3,600 hours*	↑16	Yes
Construction duration	210 days	195 days*	↓7	Yes
Workforce cost	$400,000	$360,000*	↓10	Yes
Construction waste	$8,500	$2,000*	↓77	Yes
Cost–benefit integration				Yes

* Denotes predicted values.

4.7.5 Conclusions and recommendations

This section aims to enhance the crew IRP-based bar-code system for construction M&E management by utilizing integrated GPS/GIS technology. By integrating GIS/GPS with the crew IRP-based bar-code system, real-time information on location, quantities and types of construction materials can be effectively tracked. In order to achieve this objective, the former project-oriented crew IRP-based bar-code system was first extended to an enterprise-wide construction M&E management system which was integrated to the traditional construction project management system. The extended prototype was further developed to a GPS/GIS-integrated construction M&E management system, as managers in both headquarters and construction sites have the need to get real-time information to control cargoes on the road to sites and to reduce waste generation on sites. The authors then present the conceptual model for the proposed GPS/GIS-integrated system with its logical system design and system implementation. Potential requirements and further applications are discussed as well. Finally, a case study is done to demonstrate the cost benefit of the novel system in construction. It is expected that the proposed innovation, which changes the M&E management from process-focused partial waste prevention to project-oriented total waste reduction, can dramatically improve the serviceability of the bar-code system in real-time data capture and re-use to assist the ERP implementation of construction sectors.

4.8 Conclusions and discussions

Although experimental results demonstrated the obvious strength of the group-based IRP in reducing wastage of construction materials, there has been a concern from the senior management of the contracting company in using the group-based IRP. The concern was the fear that workers might jerry-build in order to save materials, as the IRP does not directly relate itself to the quality of work. Therefore, the management felt that there is a need to investigate how to combine the quality and time performances of workers with the IRP when deciding the amount of rewards to workers. The IRP-integrated construction management has been proved to be useful and effective in the implementation of IRP.

Difficulties have also been identified during implementing the IRP on site. First, because the bar-code system can only recognize materials that have the standard quantity and does not automatically accept returned bits and pieces, quantities of the returned materials have to be assessed by the store keeper and be manually entered into the computer. This can potentially bring inaccuracies into the system. Second, as different groups may withdraw same materials, misunderstanding and conflicts between groups may occur if materials of one group are moved or mistakenly used by members of other groups. This problem will be intensified in situations with congested working spaces. These problems need to be resolved before the group-based IRP can be fully accepted and endorsed by the industry.

This chapter presents a group-based IRP, which encourages workers to reduce avoidable wastes of construction materials on site. The IRP is based on the principle of motivating workers through giving them performance-based financial rewards. Because of the unique situation in Hong Kong, this study did not consider other factors that may influence the generation of on-site wastes, such as design coordination and site supervision. Therefore, further studies are needed to test the usability of the IRP in other countries. In addition, this chapter introduces the use of a bar-code system to register the flow of materials so that performances of working groups in terms of material wastage can be easily measured. In order to avoid jerry-building, further research is needed to integrate the IRP with quality and time management.

This chapter also uses an integrated GPS/GIS technology in the reduction of construction waste and the increase of efficiency in project-oriented construction management. There are two relevant sections to describe the application in this chapter. First, a system prototype is developed from an automatic data capture system such as the bar-coding system for construction M&E management onsite, whilst the integrated GPS/GIS technology is combined with the M&E system based on the WAN. Second, a case study is done to demonstrate the deployment of the proposed application. Besides the presentation of the conceptual model, the logical system design, and the system implementation of the integrated M&E system, it is expected that the proposed innovation, which enhances the M&E management from process-focused partial waste prevention to project-oriented total waste reduction, can dramatically improve the serviceability of the bar-coding system in real-time data capture and re-use to assist with the ERP implementation of the construction sector.

Chapter 5

Effective reduction at post-construction stage

5.1 Introduction

As a modern way to conduct business in the global economic environment, e-commerce is becoming an essential component integrated with traditional business processes in enterprises. In order to reduce risks and increase profits in e-commerce investments and provide the best services to their customers, enterprises have to find appropriate approaches to analyse their e-commerce strategies at business planning stage. Strategic management tools are designed for enterprises to evaluate their business strategies and they can be used to evaluate the e-commerce business plan as well. For example, the SWOT (strengths, weaknesses, opportunities, and threats) analysis is regarded as a popular way to evaluate an e-commerce business plan, with business environmental scanning based on internal environmental factors (strengths and weaknesses) and external environmental factors (opportunities and threats) (Turban *et al.* 2003). In order to facilitate the application of the strategic management tools, different forms of applications are adopted, such as checklist (OGC 2004), rating system (UNMFS 2004), and expert system (PlanWare 2004), etc. Among these strategic management tools, computer-driven business simulation tools enable participants to run virtual business processes, experiment with different strategies, and compete with other companies or plans in a virtual business environment. As an example, the Marketplace (ILS 2003; IDC 2004) is a business simulator for integrative business courses, which provides decision-making content on marketing, product development, sales force management, financial analysis, accounting, manufacturing, and quality management. Regarding the application of computer simulation in e-commerce, the Marketplace strategic e-commerce simulation is designed specifically for e-commerce courses, and it illustrates the business concepts of the e-commerce environment (ILS 2003). For an e-commerce system simulation, Griss and Letsinger (2000) conducted research on flexible, agent-based e-commerce systems with an experimental multi-player shopping game, in which agents represent buyers, sellers, brokers, and services of various kinds, for demonstration and educational value, for experimenting with alternative individual and group economic strategies, and for evaluating the effectiveness of agent-based systems for e-commerce. Both academic and professional practice have proved that using computer-driven simulation is an effective, efficient, and economical way for e-commerce business plan evaluation.

However, it is hard to conduct simulation based on the detail flowchart of business processes within the current e-commerce simulation environment as mentioned above. This actually limits the application of e-commerce simulation. In fact, computer simulation has been applied to tackle a range of business problems, leading to improvements in efficiency, reduced costs, and increased profitability since the 1950s (Robinson 1994). During this period, the use of simulation software tools was on the rise in various application areas (Google 2005) and process-oriented simulation had become popular in business management (Swain 2001). The authors believe that a process-oriented simulation for e-commerce system evaluation is more directly perceived through the human sense, and their interest is to conduct a quantitative approach to e-commerce system evaluation based on the theory of process simulation.

The e-commerce system simulation is an integrative procedure to run a business-process-oriented simulation programme based on both internal and external business environmental factors to demonstrate the actual results of implementing an e-commerce business model by using computer-driven software toolkits. The e-commerce system simulation is an effective, efficient, and economical approach, and can be used to experiment e-commerce business models and to evaluate different e-commerce business plans, in which quantitative analysis is required by decision-makers. The adoption of e-commerce system simulation can overcome some limitations in e-commerce system development such as the huge amount of initial investments of time and money, and the long duration from business planning to system development, then to system test and operation, and finally to exact returns; in other words, the proposed process oriented e-commerce system simulation can help currently used system analysis and development methods to tell investors in a very detailed way about some details of keen interest such as how good their e-commerce system could be, how many investment repayments they could have, and which area they should improve from initial business plans.

The definition of the e-commerce system simulation has actually normalized a procedure to apply process simulation to run an e-commerce model at system-design stage. In this regard, this chapter will focus on the adaptation of an e-commerce model into a process simulation environment. And the authors achieve this through experimental case studies with an e-commerce business plan, called Webfill, for online C&D waste exchange in Hong Kong. The methodologies adopted in this chapter are literature review, system analysis and development, simulation modelling and analysis, and case study. Results from this chapter include the conception of e-commerce system simulation, a comprehensive review of simulation methods adopted in e-commerce system evaluation, and a real case study of applying simulation to e-commerce system evaluation. Furthermore, the authors hope that the adoption and implementation of the process simulation approach can effectively support business decision-making and improve the efficiency of e-commerce systems.

5.2 Background

Generally speaking, C&D waste can be reduced by using innovative construction techniques and management methods, such as adopting prefabrication and installation technologies, recycling C&D debris, reducing the possibility of waste generation in architecture and structure design, and improving site-based materials management, etc. Although these approaches have proved to be effective to some extent, most of them are still in a stage of research, and contractors usually do not like to invest in high-cost techniques and approaches if they were not forced to do so. For example, surveys show that local constructors in Hong Kong feel it is expensive to use new machinery and automation technology (Ho 1997); most (68–85%) local constructors agree to adopt alternative low-waste but high-cost techniques only when they are demanded by the designers, the specifications, or the clients (Poon and Ng 1999). As a result, C&D wastes are normally not controlled effectively on construction and demolition sites in Hong Kong. According to statistical data, C&D debris frequently makes up 10–30% of the waste received at many landfill sites around the world (Fishbein 1998), but this figure has been over 40% in recent years in Hong Kong (refer to Table 5.1).

In contrast to the percentage in other advanced countries, for example, C&D debris makes up only 12% of the total waste received at Metro Park East Sanitary Landfill of Iowa State in the United States (MWA 2000); the quantity of C&D waste in Hong Kong is about three to four times higher. So there is an urgent need to deal with the problem and to find a practical solution for C&D waste reduction in Hong Kong.

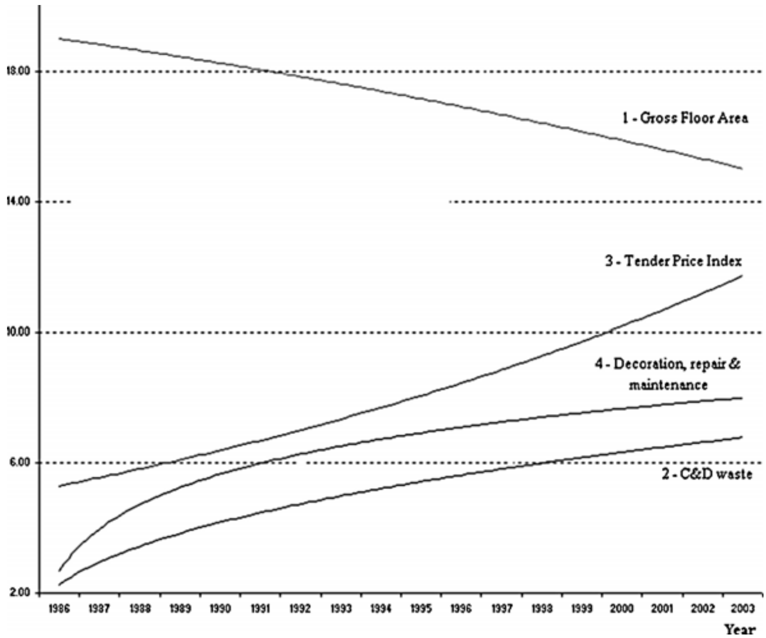
Table 5.1 An analysis of C&D waste disposal in Hong Kong (HKEPD 1999a,b,c,d/2004a,b)

Year	*Amount of waste disposal at landfills (ton/day)*		*Percentage of C&D waste (%)*
	C&D waste	*Total waste*	
1998	7,030	16,738	42
1999	7,890	17,932	44
2000	7,470	17,786	42
2001	6,410	16,686	38
2002	10,202	21,158	48
2003	6,728	17,757	38
Average	7,621	18,010	42

One of the most important C&D waste control regulations in Hong Kong is the trip-ticket system (TTS) for disposing waste from work sites to disposal facilities and landfills, which was originally recommended in the *Waste Disposal Ordinance & Waste Disposal (Chemical Waste) (General) Regulation* in Hong Kong in 1998, and was formally adopted in the Hong Kong construction industry on July 1, 1999 (HKEPD 1999a,b,c,d). The aim is to control illegal dumping and ensure proper disposal of C&D waste at public filling facilities or landfills. The TTS is a system for recording orderly disposal of C&D waste to disposal facilities by trucks. Under the TTS, contractors are required to fill in a standard trip-ticket form outlining the details of the transportation vehicle, type and approximate volume of waste, and the designated disposal facility which has been approved by the Public Fill Committee or the Director of Environmental Protection of the Government (CED 2002). Once the C&D waste is delivered to the designated facility, a receipt is issued to the vehicle operator for returning to the project engineer or architect representative for verification of the contractor's compliance with the policy requirements, and the contractors are then charged based on their receipts by the disposal facilities. The TTS is implemented to ensure a certain level of accountability among the project proponent, engineer/architect, and the contractor. Moreover, it facilitates the recording of waste as it arrives at the landfill or public filling area and minimizes the potential for cross-contamination with other waste which the vehicle operator may otherwise likely pick-up and route to the disposal facility. The TTS assumes that the contractor will bear the responsibility for the sorting (where applicable) of the C&D material generated on their site prior to its disposal.

According to the environmental permit conditions to construct and operate a designated project in the *Hong Kong Environmental Impact Assessment Ordinance*, the disposal of C&D waste should be controlled through the TTS and the records should be readily available at all times for inspection at all site office(s) covered by the Environmental Permit (HKEPD 2000a,b,c). As a result, hundreds of public-works project contracts and Housing Authority contracts invited have applied the TTS following their environmental permits in Hong Kong, and each of them obtained an admission ticket from the Facilities Management Group of the EPD for disposal of contaminated soil at landfills. From the environmental impact reports submitted recently by contractors in Hong Kong (HKEPD 2002a,b,c), the TTS is used to audit C&D waste disposal records to ensure that the number of vehicles/trucks leaving the construction site corresponds with the number of deliveries at the landfills. An on-site environmental team is normally set as an independent checker to audit the implementation of the TTS and ensure proper disposal and avoidance of fly tipping.

On the other hand, generally, the development of real estate in urban areas directly leads to the increase of C&D waste; so a great deal of efforts have been made by both academics and professionals to reduce on-site waste during construction. Although governmental audiences and industrial practice to reduce C&D waste are ordinarily known and construction contractors are encouraged



Data resource: Census & Statistics (Department (CSD) and Environment Protection Department (EPD), HK SAR)

Figure 5.1 A statistic chart of C&D waste and real-estate development in HK.

to apply environmental management on site, the reason why C&D waste keeps increasing has not been made clear. However, a statistic analysis as presented in Figure 5.1 reveals that there is a remarkable divergence between the bullish tendency of C&D waste generation and the bearish tendency of real-estate development in Hong Kong since the mid-1980s, and this evidence indicates that the scale of construction in real-estate development may not play a leading role in generating C&D waste. On the other hand, the statistic analysis also reveals that synchronous tendencies exist between trend-line 2 and trend-line 4 in Figure 5.1, which indicates that building decoration, repair, and maintenance works are a real leader in generating C&D waste in Hong Kong. As the authors did not extend this statistical analysis outside the Hong Kong construction industry, it is not rational to conclude that most part of C&D waste is generated due to renovation works of buildings in a worldwide scale; however, the statistic analysis emphasizes the importance of considering property management activities at post-construction stages in the C&D waste exchange process.

The Government of the Hong Kong Special Administrative Region (HKSAR) has proposed to implement a C&D waste management strategy in the *Government Plan 1999–2007*, which is essentially to avoid, minimize, recycle, and dispose of waste based on desirability. The target of the strategy is to reduce the generation of C&D waste and hence its intake at landfills, and to re-use and recycle as much C&D material as possible. Similar to the *C&D Debris Management Program* that has been put into practice at the Metro Park East Sanitary Landfill site since 1995 in the United States (MWA 2000), tipping fee (HK$125 [about US$16] per ton) on C&D waste taken to landfills is imposed in Hong Kong since 1999, when the Environmental Protection Department (EPD) of the HKSAR government established an administrative TTS in public-works project contracts for the proper disposal of C&D waste at public filling facilities or landfills (HKEPD 1999a,b,c,d). Benefits of implementing this strategy include potential savings for landfill sites, proper disposal of C&D waste, and reduction of waste generation on site. However, it is reported that the TTS encounters obstacles when waste transporters are asked to pay disposal charges for contractors who are the generators of the C&D waste, and transporters are finally permitted legally to dispose the waste without any payment if they can make a written or even an oral pledge that contractors have not paid for them (Mingpao 2002). This legal loophole indicates it is necessary to improve the TTS through better managing the flow of waste disposal.

Although the authors have not found any report on how much C&D waste has been recorded and how much C&D waste has been reduced due to the implementation of the TTS in Hong Kong, it is not difficult to find out that the TTS's contribution is limited in the whole C&D waste cycle. The main feature of a C&D waste cycle with a smooth movement and operation is that it must be a valued-added chain, where all participants including construction contractors, property managers, material manufacturers, waste material recyclers, landfill managers, etc. can get benefits. However, the TTS can only record about waste conveyance between construction sites and landfills, and it seems to have no direct contribution to the value-added chain, even to the reduction of C&D waste. Specifically, main weaknesses of the TTS exist in the following four aspects:

1 current TTS is only implemented in public construction projects, and the disposal of the C&D waste generated from private construction projects is not controlled;
2 although the TTS tracks the results of C&D waste disposal, information of waste tracking is not used effectively in waste management;
3 tipping fee of C&D waste can be waived as an expedient; and
4 the TTS increases the amount of paperwork.

The EPD of the HKSAR government has been attempting to resolve the last two weaknesses by introducing new legislations and a smart card system. This chapter focuses on introducing an e-commerce system called Webfill, which is an online portal for C&D waste trade, so that all participants can benefit from using this system.

In order to deal with these problems in C&D waste management in Hong Kong, this chapter proposes to apply an e-commerce model for C&D waste exchange to enhance efficiency and effectiveness of the TTS and accordingly to reduce the total amount of C&D waste disposed to landfills in Hong Kong. For fear that the e-commerce model would not provide an ideal result, a simulation-based comparison between the existing TTS and the enhanced TTS is conducted. With the only view of reducing the C&D waste in Hong Kong, the e-commerce model or the waste exchange model can only work for reducing the already generated C&D waste, while generation of the waste cannot be expected to be controlled with it. As a result, this chapter only focuses on the e-commerce model for the C&D waste reduction on a post-construction stage.

5.3 Online waste exchange approach

5.3.1 Feature comparison of waste-exchange websites

The concept of waste exchange systems for exchanging industrial residues and information, and for reducing the waste volume was introduced in the 1970s (Middleton and Stenburg 1972; Mueller *et al.* 1975). In recent years, Web-based services for waste material and equipment trade and information exchange have been developed as they support effective multimedia communication. Online search results show that there are a number of websites related to waste exchange, and some of them also provide in advance a special area for quality salvaged C&D waste at comfortable prices on their websites; however, it is apparent that no website has been found to be solely dedicated to e-commerce of C&D waste exchange. For a website review, Appendix C summarizes 36 online C&D waste-exchange-related websites. According to relevant information from these websites, the authors made a short comparison study based on criteria described in Table 5.2, and Figure 5.2 shows a statistic comparison of these websites.

Based on the website review, the authors noticed that there is a general online C&D waste exchange model, adopted by most of the observed websites, which

Table 5.2 Feature comparison of C&D waste exchange websites

Website name	*Market*	*Functions*					*Charge*	*Condition remarks*
		Search	*List*	*Add data*	*Trade online*	*Membership*		
Website 1	Local/Global	✓/x	✓/x	✓/x	✓/x	✓/x	Free/Not	Working/Not
Website 2	Local/Global	✓/x	✓/x	✓/x	✓/x	✓/x	Free/Not	Working/Not
. . .								
. . .								
Website *n*	Local/Global	✓/x	✓/x	✓/x	✓/x	✓/x	Free/Not	Working/Not

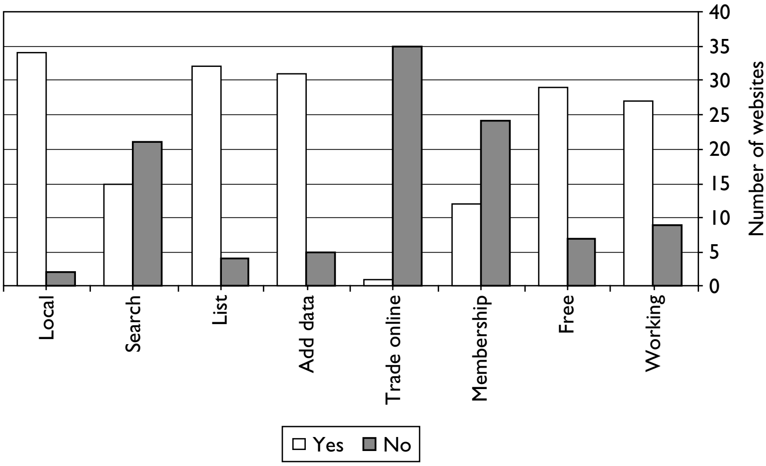


Figure 5.2 Feature comparison of C&D waste exchange websites.

can be developed based on their common features summarized in Figure 5.2. Although there are some differences among their profile designs, common features exist in data transfer and website functionalities.

5.3.2 Operation obstacles

The websites for waste exchange have generally proved to be useful and effective in reducing total industrial waste. For example, since 1992 more than 650,000 tons (Note: this figure remains unchanged in 2002) of materials have been diverted from landfills and over 5.5 million dollars have been saved through the CMX (CMX 2000). However, it has also been found that information about C&D waste or the number of contractors who want to buy second-hand materials or C&D waste is very limited. For instance, search results of the CMX show that there are no date records about every available material and there is no buyer requesting C&D waste materials (CMX 2000), and this situation recurs in other observed websites (accessed between 2000 and 2003), e.g. HappyHarry's, HIMAX, and MaterialsExchange, etc. To quote examples for the status of online C&D waste exchange, HappyHarry's provides for used building materials exchange on the Internet; although there are about 51 records on the webpage under item "View list", record numbers are only available from 970728-1 to 971205-2, and these numbers indicate that there might be no recent records, and it has not worked effectively since 1998. The HIMAX was in a similar situation, where only records of 1996 can be found; and MaterialsExchange is another website providing services for C&D waste exchange, where similarly, only two records were found on its material list, and the records were last revised on

April 11, 1999. From these observations, it is reasonable to assume that websites for waste exchange are not widely accepted in the construction industry, and the main suspected reasons are given below:

1 contractors pay less attention to C&D waste reduction;
2 contractors can make little profit by using waste exchange;
3 information of waste exchange is scattered on many different websites; and
4 websites lack user-friendly/efficient operational mechanism's to pull users.

The main problem of subsidence of online C&D waste exchange comes from contractors, who pay less attention to C&D waste reduction. Over a long period of time, contractors have been accustomed to conventional project management, including cost management, time management, and quality management, and environmental management during project construction is relatively new to them. In many developing countries, contractors are still allowed to transport their C&D waste to landfills for free, rather than using a Web-based tool to find the best ways of recycling C&D waste and which delivers customer requests directly to contractors' desks.

Another problem is that contractors make little profit from using waste exchange systems. In many parts of the world, contractors have to pay for disposing of C&D waste to landfill sites, and contractors are being pressured to reduce the C&D waste discharge. Under this circumstance, a Web-based C&D waste exchange site becomes necessary to contractors as the website can disseminate information about C&D material which could be reusable by other people. According to statistics from the Portland area in the USA, there were approximately 550,000 tons of C&D wastes (about 145,000 drop box loads) in 1994. While garbage-dumping fees are US$62.50 per ton, over 50% of the C&D waste can be diverted to a recycler (buyer) for incomes ranging from nothing to US$35 per ton (Metro 1997). By using an online C&D waste exchange system, contractors can sell their residual materials to other contractors or manufacturers or recyclers to reduce their C&D waste disposal costs and conserve resources. However, the current Web-based information exchange model only provides contractors an information-exchange platform. No matter whether they want to sell or buy, contractors and manufacturers will have to wait with patience for feedback information from each other, and this often leads to delays in construction or manufacture processes. So contractors often have to give up the benefit from selling out their C&D waste in order to meet the tight construction schedules, even if there are enough temporary rooms for C&D waste storage on site. In fact, there are often not enough places to pile up on-site residual C&D materials, and they are often treated as landfill waste as it is cheaper to do so.

Moreover, the problem associated with websites themselves is that there are too many websites with similar functionalities of waste exchange. Contractors can easily get confused to choose a suitable system. Moreover, the lack of user-friendly and efficient operational mechanisms often make current waste exchange websites unattractive. The authors also noticed that there was no waste exchange website that handles both Chinese and English in the user interfaces. Because of these, most waste-exchange websites could not attract enough users.

Nevertheless, the potential of waste exchange websites in disseminating information between contractors and buyers is well recognized. Because of the identified weaknesses of the TTS and the unattractiveness of existing waste exchange websites, the authors set to develop their own waste exchange website and integrate it with the TTS.

5.3.3 An e-commerce model

E-commerce has grown quickly in the construction industry as it is value-adding to business processes in the construction industry (DeMocker 1999; Berning and Diveley-Coyne 2000; NOIE 2001; Waugh and Makar 2001). According to the business model adopted, e-commerce systems can be categorized into three types: business-to-business model (e.g. e-IDC.com), business-to-customer model (e.g. Build.com), and combinatory model (e.g. EI-Internets.com). Because the business-to-business model has proven to be sustainable and profitable in the e-market of construction industry, it is most commonly used to develop E-commerce systems (Lais 1999), and more than 90 percent of architects, designers, and contractors expect to conduct more business over the Internet (Mark 2000). The authors thus select the business-to-business model to develop their online C&D waste-exchange system, which will be integrated with the TTS.

It should be mentioned that there is a waste-exchange website developed by the Environmental Protection Department of the HK Government in 2000 for C&D material management, from which practitioners in the Hong Kong construction industry can obtain useful information on waste minimization (WRC 2000). The developed website, named "C&D Material Exchange" (HKEPD 2002a,b,c), is open on the Internet. However, the system is incomplete when compared with other online waste-exchange websites such as those mentioned in Appendix C. For example, no list and search functions are provided in the system. In this regard, there is real potential to set up an online C&D waste exchange portal for the Hong Kong construction industry, and the authors attempted an e-commerce system as described below.

5.4 Integrated TTS-based e-commerce

5.4.1 Webfill model

Webfill is the e-commerce model for C&D waste exchange in Hong Kong developed by the authors, and it has been further developed to an online C&D waste exchange portal for the Hong Kong construction industry. Regarding the model design, different business models have been considered by the authors under the criteria to maximize recycle.

Rappa (2002) has summarized two essential strategic models for online exchange business including brokerage model and infomediary model. The brokerage model, e.g. Marketplace Exchange, provides a full range of services covering the transaction process, from market assessment to negotiation and fulfillment, for a particular industry. The exchange can operate independently of the industry, or it can be backed by an industry consortium. The broker typically charges the seller a transaction fee based on the value of the sale. There may also be membership fees. On the other hand, the infomediary model, e.g. Metamediary, facilitates transactions between buyers and sellers by providing comprehensive information and ancillary services, but does not get involved in the actual exchange of goods or services between the parties. Based on this theory, the infomediary model is finally selected for the integrated TTS-based e-commerce system.

Figure 5.3 illustrates the Webfill model with an information flowchart. The flowchart takes into account the common features of C&D waste exchange systems summarized in Figure 5.2 as well as the functional requirements of e-commerce.

Based on the background information mentioned earlier, the authors designed the Webfill model for five groups of main participants – construction contractors, property managers, manufacturers, recyclers, and landfill managers. The Webfill system is designed to provide member-oriented services such as add exchange information to the system, search for information for decision-making, and trade based on search results (trade options can be to sell waste or residual materials, to buy second-hand materials, to buy recovered or recycled materials), etc. An

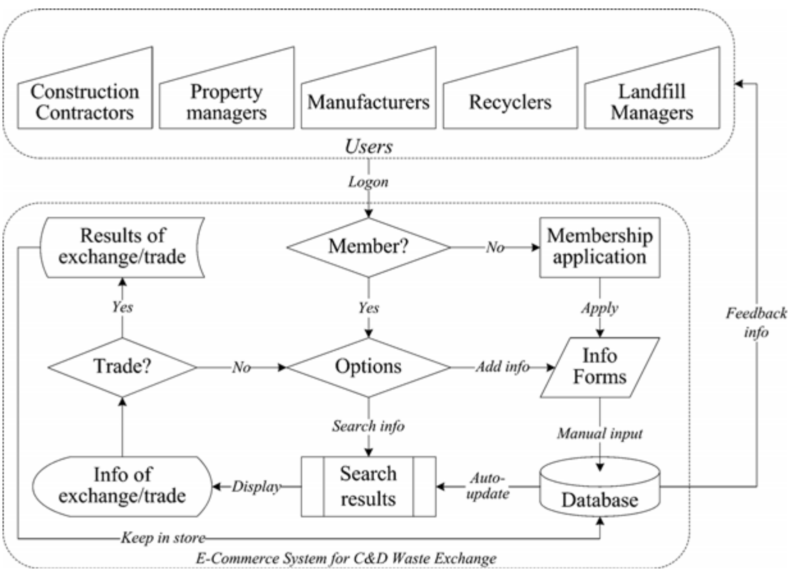


Figure 5.3 Webfill e-commerce model for C&D waste exchange.

e-commerce server is designed to support the Webfill system, and all C&D waste information will be put into a database. E-mail service is used to link users and the Webfill system, and all membership information and trade information, etc. will be sent to each user from the database via e-mail. In addition, a credit card based online payment system is also adopted in the Webfill system to facilitate trade processes.

5.4.2 Users and their benefits

As mentioned earlier, there are five groups of potential users of the proposed Webfill system. Among them, construction contractors and property managers are providers of the C&D waste as well as the consumers of residual or second-hand materials, and recovered or recycled materials; manufacturers are providers of new materials made from raw materials or from C&D waste debris; landfill managers are providers of recyclable C&D waste debris, second-hand materials, and backfill materials, etc.; and recyclers are businessmen working among the construction contractors, the property managers, the manufacturers, and the landfill managers to provide them information and transportation services. Table 5.3 describes the five kinds of users and their key roles together with benefits they can gain by using the Webfill system.

Benefits of using the Webfill system can be further elaborated as follows. First, as the TTS forces contractors to look for an inexpensive way to dispose of their C&D waste without paying tipping fees, the contractors can use the Webfill system in their best interests to find a buyer(s) for their residual construction

Table 5.3 The usefulness of the Webfill system

Users	*Roles*	*User requirements*		*Benefits*
		Sell	*Buy*	
Construction contractors	Waste generator	Recyclable waste Residual materials	Recovered materials Residual materials	Reduce tipping fee Reduce wastage Save on buying materials
Property managers	Waste generator	Recyclable waste Residual materials	Recovered materials Residual materials	Reduce tipping fee Reduce wastage Save on buying materials
Manufacturers	Material make Waste recovery	Recovered materials	Recyclable waste; Residual materials	Save on buying raw materials Increase sell
Recyclers	Waste trade	Recyclable waste Residual materials Recovered materials	Recyclable waste Residual materials Recovered materials	Increase waste re-use
Landfill managers	Waste disposal Waste trade	Recyclable waste	N/A	Decrease disposal of waste

materials, who may be other contractors, manufactures, or recyclers. Contractors can also buy residual or used materials and equipment from other contractors, or buy inexpensive recovered materials from manufacturers, or deal with recyclers, in order to lower construction costs. Second, manufacturers can either sell their low-cost products made from recovered materials on the Webfill system at attractive prices to contractors, or buy cheaper raw and processed materials and used equipment from contractors. Recyclers and landfill managers can also sell their recovered products to contractors or manufacturers. Third, recyclers can either sell second-hand materials to contractors and manufacturers on the Webfill system, or buy cheap materials from contractors. Last but not least, landfill managers can either sell recyclable or recoverable materials to manufacturers and recyclers at low prices or free of charge on the Webfill system in order to reduce the total amount of C&D waste tipped at public filling facilities. Consequently, the Webfill system is able to attract construction contractors, property managers, manufacturers, recyclers, and landfill managers to work together as the Webfill system creates a win-win situation for all of them.

The Webfill system provides members a group of functions in e-commerce selections (refer to Appendix D). All selections are combined together according to the generic e-procurement process of Webfill that is described in Figure 5.3, and a demonstration website for local C&D waste exchange was located at http://158.132.107.159/mm/index.asp(2000/2003).

5.4.3 Website flexibility

5.4.3.1 Membership

Users are required to register to become members of the Webfill system. After registration, Webfill provides every member with a trade account. A Webfill member can use the account ID and the self-determined password to login. Members enjoy a range of services including updated information on residual and reusable materials available, and functions for searching, ordering, selling, auctioning, and bidding of materials. The Webfill system automatically records the trading details of each member, which can further provide useful information for members to sell or buy materials. The trading records of a member are also used to assess his or her contribution to reducing C&D waste, and an annual reward system is used to encourage and reward active members.

5.4.3.2 Commission fee

Incomes for the Webfill system can be generated in two ways: one is commission fee and another is advertisement fee. Webfill charges 0.1% of commission fee from each successful transaction. Every member is asked to provide the credit card information to prevent the evasion of commission fees. When the Webfill system sends email notification with a trade receipt to the seller and the buyer, as shown in Figure 5.3, the commission fee will be charged automatically from the seller's credit card account. If a buyer is not satisfied with what he ordered according to the Webfill's information and does not conclude the transaction with the seller, he can inform the Webfill system and the commission fee is then released.

5.5 Webfill simulation

Although a demonstration website of Webfill was developed, whether Webfill can really play the expected role in C&D waste reduction in Hong Kong is still a question. Besides research initiatives in a questionnaire survey form regarding the acceptance of the Webfill system, the Webfill model recalls a business process system, and the authors thus try to adopt the concept of e-commerce system simulation to experiment the Webfill system based on process simulation with statistical parameters relating to the generation, re-use, recycle and disposal of C&D waste in Hong Kong. The simulation which enables the authors to evaluate the performance of the Webfill system by comparing the results from two models, simple TTS and Webfill-enhanced TTS, is conducted. Considering the specific characteristics of the process flowcharts of the TTS and the Webfill system (refer to Figures 5.3–5.5), a commercial simulation software, i.e. ProcessModel (processmodel.com) is selected as the tool to simulate the simple TTS and the Webfill-enhanced TTS.

5.5.1 Simulation models

There are two basic steps involved in developing a simulation model: one is to establish a process model for simulation and another is to set some basic parameters according to real conditions. A process model is a process flow diagram that uses associated data to describe a real-life process, where objects (graphic shapes) and connections (lines connecting the graphic shapes) are used to represent process elements and relationships, respectively. In order to compare the simulation results between the TTS and the Webfill-enhanced TTS, two process-based simulation models are illustrated in Figures 5.4 and 5.5.

Figure 5.4 illustrates a simple TTS-based simulation model. There are ten entities in this model: *Materials* for both public buildings and private buildings, *Buildings* and *Civil Works* for the built environment, *Public Projects* for construction of public buildings, *Private Projects* for construction of private buildings, *On-site waste classification and storage* from both public and private projects, *Waste Recovery* at building material manufactories, the *TTS*, *Pre-landfill* for waste re-classification and storage, and *Landfill* for permanent waste disposals. All these entities are treated as processes inside the model, and the relations between any two entities are described using arrow lines with keyword indications.

Figure 5.5 illustrates the proposed Webfill-enhanced TTS simulation model. In addition to the ten entities inside the simple TTS-based simulation model,

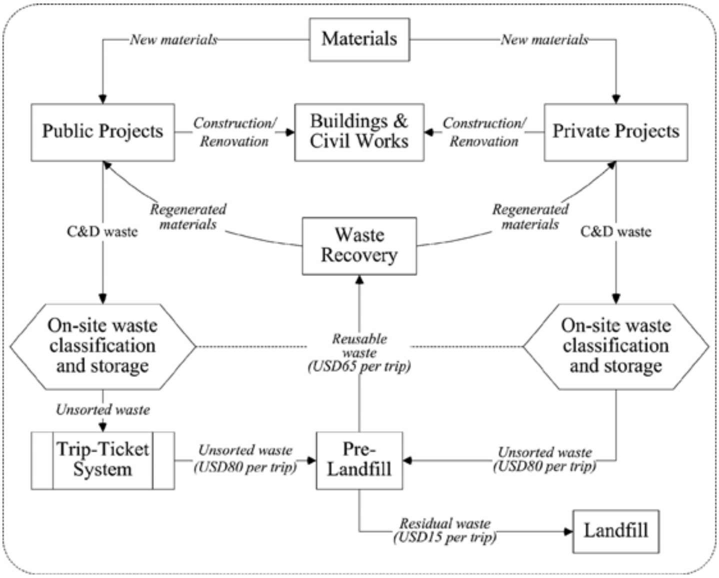


Figure 5.4 A simple TTS-based simulation model.

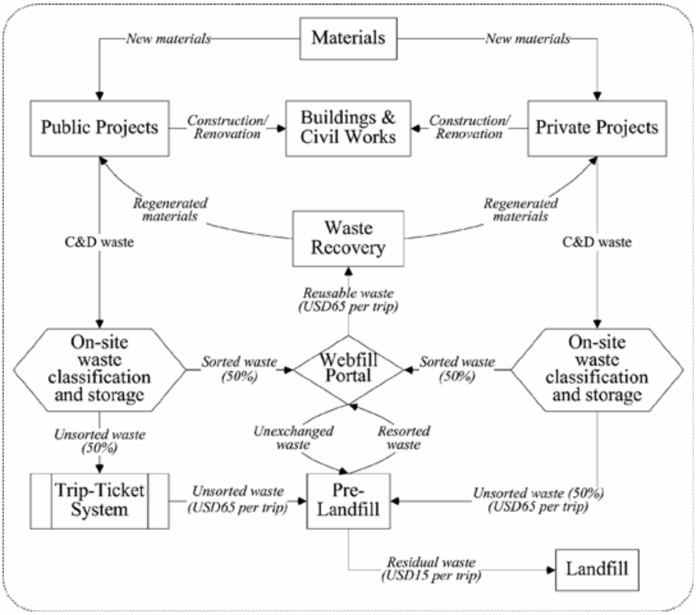


Figure 5.5 A proposed Webfill-enhanced TTS simulation model.

illustrated in Figure 5.4, a new entity of *Webfill* is integrated with the simple TTS-based simulation model. As the *Webfill* entity aims to introduce e-commerce into current TTS-based C&D waste management processes, this integration directly makes changes to the whole material chain in the Hong Kong construction industry. The influences include the following:

- for the two *On-site waste classification and storage* entities, Webfill divides part of C&D waste into e-commerce processes;
- for the *Waste Recovery* entity, Webfill interposes among the entities of *Waste Recovery*, *On-site waste classification and storage*, and *Pre-landfill* so as to provide more options to facilitate the recycle of C&D waste from construction sites and landfills; and
- for the *Pre-landfill* entity, Webfill provides a bridge to lead C&D waste disposed to the landfills back to the materials cycle.

Similar to Figure 5.4, all entities in Figure 5.5 are treated as processes inside the model, and relations between any two entities are described using arrow lines with keyword indications.

Regarding the five main participants involved in the two models – construction contractors, property managers, manufacturers, recyclers, and landfill managers – each of them occupies the relevant entity/entities inside the two models. For example, construction contractors and property managers have the same entities of *Public Projects*, *Private Projects*, and *On-site waste classification and storage*, etc; landfill managers have the entities of *Pre-landfill*, and *Landfill*; manufacturers have the entities of *Materials* and *Waste Recovery*. Although Figures 5.4 and 5.5 do not give entities to recyclers, it is generally regarded that recyclers can participate in the waste exchange at the entities of *Materials*, *Public Projects*, *Private Projects*, *On-site waste classification and storage*, *Waste Recovery*, *TTS*, and *Pre-landfill* to provide useful information on C&D waste recycle to other participants.

5.5.2 Basic parameters

Parameters have to be valued before running simulations based on the two models. In order to make a comparison between the two models as described in Figures 5.4 and 5.5, the authors decided to use the same set of parameters. Table 5.4 provides a list of some basic parameters selected for simulation, and Figures 5.4 and 5.5 provide necessary information for parameter settings. In addition to these parameter settings, the authors assume that the quantity of C&D waste ($G_{\text{C\&Dwaste}}$) generated by either the *Public Projects* or the *Private Projects* follows a normal probability distribution, and it is calculated using Equation 5.1.

$$G_{\text{C\&Dwaste}} = 0.036 \times \mathrm{N}(20, 5) \quad (5.1)$$

Table 5.4 Parameters for the comparison simulation

Adjusted items	*System parameters*	*Real characteristics*	*Simulation settings*
Process duration	40 hour	8 years (300 working days/year)	1 min = 1 day
Waste quantity	1 unit	22,000 tons/day (Mean value of the statistic data from 1998 to 2003)	1 unit = 11,000 tons waste rate is 3.6% $0.036 \times N(20,5)$

The assumption is made based on the details of the amount of C&D waste derived from the governmental statistic data (HKEPD 1999/2003) and relevant statistical analysis conducted by the authors.

5.5.3 Simulation results

Each simulation process sustains for about 25 minutes in Microsoft Windows XP operating system with Intel Pentium 1 GHz CPU and 512 MB RAM. Although the parameters are set based on historic data, it has been noticed that the simulation actually can provide more information regarding various business circumstances. However, as the purpose of this section is to provide a case study to demonstrate the process simulation that can be used to experiment an e-commerce system, the authors will not present more details about various experiments conducted on the two simulation models in accordance with various values of each parameter and further discuss regarding how to use feedbacks from simulation processes to revise a proposed business model. In this regard, the values of all parameters are kept in their original form as mentioned in the above context; and a group of simulation results and relevant comparisons are presented in Table 5.5.

Simulation analysis shows that the implementation of Webfill system in an 8-year period provides some foreseeable results. For example, the utility of landfill decreases 85% and the TTS utility is reduced by 12%, while the utility of waste recovery increases 493%. These results indicate that the Webfill system can effectively reduce C&D waste disposed to the landfills and increase the use of recovered materials in building and civil works. Moreover, the total quantity of C&D waste is reduced by 8% on average between public projects and private projects; and the average waste cycle time increases 42%; the average value-added time of waste recovery lengthens 42%, and the average waste transportation cost increases 55%. These results indicate that the Webfill-enhanced TTS can reduce the amount of C&D waste at the landfill sites by increasing waste recovery and re-use.

The simulation reveals some unique results that other kinds of evaluation tools are unable to evaluate. This advantage is achieved by conducting process

Table 5.5 Simulation results and comparisons

Simulated Items	*Simulation results*		*Changing rates (%)*
	TTS model	*Webfill model*	
Landfill utility (%)	15.5	2.3	−85
Waste recovery utility (%)	2.9	17.2	+493
TTS utility (%)	5.1	4.5	−12
Quantity of C&D waste (unit)			
Public project	328	302	−8
Private project	336	309	−8
Average	332	306	−8
Average waste cycle time (day)			
Public project	7	10	+43
Private project	5	7	+40
Average	6	9	+42
Average value-added time (day)			
Public project	3	4	+33
Private project	2	3	+50
Average	3	4	+42
Average waste transportation cost (USD)			
Public project	90	140	+56
Private project	85	130	+53
Average	88	135	+55

simulation in e-commerce system evaluation. Although it has been proved that the Webfill-enhanced TTS is more effective than simple TTS in C&D waste reduction, simulation results also indicate that the average waste transportation cost will increase, which means that the e-commerce system for C&D waste exchange will lead to more transportation from the construction industry, and more energy consumptions indeed.

5.6 Conclusions

This chapter presents a novel e-commerce simulation using a model e-commerce system, Webfill, which is integrated with the TTS used in Hong Kong for managing C&D waste disposal. The Webfill e-commerce system provides an on-line C&D waste exchange platform between construction contractors, property managers, construction material manufacturers and recyclers, and landfill managers. In order to evaluate the performance of the Webfill-enhanced TTS e-commerce system in reducing the C&D waste, a process-based simulation is done which allows the authors to directly compare the simple TTS and the Webfill-enhanced TTS. Simulation results indicate that the Webfill-enhanced TTS apparently reduces the total amount of C&D waste, through encouraging the increase of waste recovery. It is thus suggested that the Webfill-enhanced TTS be applied in the Hong Kong construction industry in order to deal with the continuously increasing amount of C&D waste. Furthermore, the Webfill simulation experiments a new area of e-commerce business plan evaluation, in which the concept of process simulation can be successfully implemented. Further research efforts should engage in Webfill model revision based on simulation results, and consider simulation parameters as well.

The successful application of process simulation in e-commerce business plan evaluation in this chapter reveals an emerging trend in e-commerce strategic management using quantitative approaches. Because process simulation is generally accepted in business management, it is an economical way to directly use commercial process simulation package for e-commerce simulation. However, as there are some limitations in process simulation packages such as no permission for users to modify internal and external business environmental factors based on their various experiments, it is essential to use current business strategic management tools such as the SWOT analysis in e-commerce system evaluation as complements. In this regard, further research tasks are required to integrate current qualitative strategic management tools into business process simulation environment.

Chapter 6

Knowledge-driven evaluation

6.1 Introduction

The adverse environmental impacts of construction such as soil and ground contamination, water pollution, construction and demolition waste, noise and vibration, dust, hazardous emissions and odours, demolition of wildlife and natural features, and archaeological destruction have been a matter of concern since the early 1970s and are of more and more academic and professional interest in the construction industry especially after the ISO 14000 series of EM standards was enacted. In this regard, quantitative analytical approaches to EM in construction are currently not as prevalent as qualitative approaches, such as regulations and practical guides, due to the difficulties in transformation of practical data to abstract data that are necessarily used in calculation for EM. However, it is hard to accept an EMS without the background support of quantitative analytical approaches, or an EMS is not consummate if adequate quantitative analytical approaches for sustainment are not there. For the sake of practical approaches and their integrated application for quantitative EM in construction, a research project, *An Integrated Analytical Approach to Environmental Management in Construction* (Chen 2003), was set up in the Research Centre for Construction Innovation, the former Research Centre of Construction Management and Construction IT, Department of Building and Real Estate, the Hong Kong Polytechnic University in 1999 and the findings from this research project include one holistic approach and four quantitative EM tools for environmental-conscious construction project management.

The successful implementation of ISO 14001 EMS in construction sectors requires far more than just the apparent prevention and reduction of negative environmental impacts in a new project development cycle as well as each proposed construction process cycle during pre-construction stage, continuous improvement of the environmental management function based on institutionalization of change throughout an enterprise to reduce pollution during construction stage, and efficient synergisms of pollution prevention and reduction such as waste recycle and regeneration in the construction industry throughout construction stage and post-construction stage. It necessitates a complete reengineering and transformation of all organizational functions related to the project-based construction management (CM) throughout each construction stage in environment-conscious construction sectors. In addition to the integration of all stages of the construction life cycle, the effective implementation of ISO 14001 EMS in construction enterprises also demands functional tools to facilitate the deployment of the EMS throughout construction enterprises and construction projects in both macro and micro environment's for organizational sustainable development. The lack of effective EM tools and the insufficient utilization or abuse of EM tools can directly obstruct the implementation of EMS in either construction enterprises or the construction industry even though such a management system has been accredited individually in advance (Chen and Li *et al.* 2002a). For example, according to a recent statistical data analysis conducted in the Chinese construction industry (Chen and Li *et al.* 2004a), the annual rate of environmental impact assessment (EIA) approvals for new construction projects was 97% in 2001, whilst the rate of the ISO 14001 EMS accreditations for construction enterprises was as low as 1‰ in mainland China. It is obvious that approval rate of EIA is much higher than the accreditation rate of EMS in this case; however, it also discloses that most construction enterprises have not yet adopted or accepted the ISO 14001 EMS in mainland China. As the EIA approval is only required at registration stage of construction projects and the EMS implementation is normally required to be sustained during the whole period of construction projects, the disagreement existing between the two rates discloses that there may be little coordination between the EIA process and EMS implementation in construction projects, and thus the EIA may not really serve as a tool to promote EM in construction projects in the construction industry in mainland China. Although the authors have not collected enough data to support the statement that the implementation rate of mandated EIA process is universally higher than the accreditation rate of encouraged ISO 14001 EMS in the construction industry all over the world, except for the Chinese case mentioned above, some indirect evidences can be presented based on previous research reports related to the implementation of ISO 14001 EMS in construction sectors in different countries such as Australia (CPSC 2001; Zutshi and Sohal 2004a,b), China (Chen, Li and Wong 2000; Lo 2001; Tse 2001; Zeng *et al.* 2003), Singapore (Kein *et al.* 1999; Ofori *et al.* 2000), UK (CIRIA 1999), and USA (Darnall 2001; Valdez and Chini 2002), in which construction sectors emphasized that the procedure of the EIA or the EMS should be undoubtedly adopted under mandatory instructions from local governments and EM tools were specially required to facilitate the implementation of the EIA and the EMS in project-based construction management.

Regarding the EM tools for construction sectors, as quantitative EM tools are currently not as regularly adopted as qualitative EM tools such as administrative regulations and practical guides due to the difficulties in raw on-site information and data transformation for necessary computation in the EM-integrated construction project management, it is necessary to power an EMS accredited or under accreditation with adequate support from quantitative EM tools and their background knowledge warehouse, which is the essential component of an enterprise's Knowledge Management System (KMS), where knowledge is developed, stored, organized, processed, and disseminated (SAP INFO 2004). Based on this consideration, the authors want to put forward a novel methodology entitled E+ in which a KMS for environmental-conscious construction project management is integrated with EM tools and dynamic EIA process transplanted from a combination of a standard EMS process and a static EIA process. It is expected that the deployment of E+, or the knowledge-driven EMS-based dynamic EIA process, can facilitate KM initiatives for improved competitiveness of construction enterprises in EM. This holistic objective will be achieved step by step through the following four sub-objectives:

1 to illustrate an integrative knowledge-driven EM prototype to capture and re-use data, information, and knowledge for dynamic EM in construction project management;
2 to describe quantitative EM tools which can be integrated into the integrative KM model for dynamic environmental-conscious construction project management;
3 to describe an interaction of quantitative EM tools with the integrative KM model and key information techniques to for a KMS to support dynamic EM in construction project management; and
4 to demonstrate the implementation of the KMS through a case study.

First of all, an integrative methodology for dynamic EM in construction project management is developed as a comprehensive frame prototype entitled E+. Next, four quantitative approaches to be integrated into the E+ model are developed step by step. They are the analytical approaches for construction planning such as the CPI method and evaluation of environmental-conscious plan alternatives named env.Plan method, and analytical approaches for construction logistics management such as the IRP method, and construction waste exchange model named Webfill method. After that, two knowledge management entities – knowledge capture entity and knowledge re-use entity – together with six kinds of relative CM knowledge bases are unified into the E+ model aimed for integrative effectiveness and efficiency of the model. Finally, the implementation of the integrative analytical approach is demonstrated with an experimental case study.

For the integrative methodology of KMS for EM in construction, this chapter mainly contributes to existing theory or EM in construction in the area of quantitative analytical approaches and their integrative implementation. According to the literature review and questionnaire survey for this research, the lack of effective, efficient, and economical (E3) quantitative analytical approach is one of the obstacles to implementing EM in construction. Therefore, there are four points of contributions from this research to the existing theory or practice of EM in construction:

1 This research has developed an integrative methodology (E+) to implementing EMS and KM in construction, with a rigorous dynamic EIA model based on various functionally different approaches to EM in a construction

cycle. The E+ prototype was originally created in both the theory and practice for EM in construction, and it is open to further integration of various functionally different approaches for EM in construction other than the three EM tools presented in this chapter. Because the E+ is both EMS-oriented and process-oriented in construction, it can help contractors to implement EM from a messy situation to a normalized system and to effectively share EM knowledge and information internally and externally.

2 The CPI method integrated in the E+ model is a quantitative approach to predicting and levelling complex adverse environmental impacts potentially generated from construction and transportation due to the implementation of a construction plan. As a result, the CPI method has been integrated into E+ EM Toolkit A, one functional section of E+ system, to carry out the task in environmental-conscious construction planning.

3 The IRP method is a quantitative approach to reducing wastage of construction materials on a construction site, and it is designed to be effectively implemented by using a bar-code system. The IRP is then integrated in the E+ EM Toolkit B, another functional section of E+, as a basic component.

4 The Webfill method is an E-commerce model designed for the trip-ticket system to effectively reduce, re-use, and recycle C&D waste. Although there is lack of data to prove the efficiency in reality, the computer simulation results and a questionnaire survey from another research (Chen 2003) have proved that the Webfill system can effectively realize the design function. As a result, the Webfill is also integrated in the E+ model as an important component of the E+ EM Toolkit C.

The authors expect that readers can obtain state-of-the-art socio-technical perspectives from the introduction of the E+ prototype and its Toolkits, and know how E+ can work for a dynamic EIA process in construction with integrated supports from E3 quantitative analytical approaches in the Toolkits.

6.2 Background

EM in construction has received more and more attention since the early 1970s. For example, studies on noise pollution (U.S.EPA 1971), air pollution (Jones 1973), and solid waste pollution (Skoyles and Hussey 1974; Spivey 1974a,b) from construction sites were individually conducted in the early 1970s. Although the expression of EM in construction came out in the early 1970s after the U.S. National Environmental Policy Act of 1969 enacted (Warren 1973), the concept of EM in construction was introduced in the late 1970s, when the role of environmental inspector was defined in the design and construction phases of projects to provide advice to construction engineers on all matters in EM (Spivey 1974a,b; Henningson 1978). However, there had been little enthusiasm for establishing an EMS in construction organizations until two main important standards, BS 7750 (released by the BSI Group in 1992) and the ISO 14000 series (released by the ISO in 1996), were promulgated to guide the construction industry from passive CM on pollution reduction to active EMS for pollution prevention.

In the 1990s, the CIRIA conducted a series of reviews on environmental issues and have undertaken initiatives relevant to the construction industry after the introduction of BS 7750 (Shorrock *et al.* 1993; CIRIA 1993, 1994a,b, 1995; Guthrie and Mallett 1995; Petts 1996). Thereafter, research works on EM have also focused on the implementation of EMS and the registration of ISO 14001 EMS by authoritative institutions in the construction industry, such as the CIOB (Clough and Antonio 1996), the FIDIC (1998), the Construction Policy Steering Committee (CPSC 1998), and the CIRIA (Uren and Griffiths 2000).

In order to assess the extent of EMS implementation within the construction industry, several investigations have been conducted independently by researchers in different countries since 1999. For example, Kein *et al.* (1999) conducted a field study in Singapore to assess the level of commitment of ISO 9000-certified construction enterprises to EM. They found that contractors in Singapore were aware of the merits of EM, but were not instituting systems towards achieving it; Ofori *et al.* (2000), also in Singapore, then conducted a survey to ascertain the perceptions of construction enterprises on the impact of the implementation of the ISO 14000 series on their operations. Major problems were identified, such as the shortage of qualified personnel, lack of knowledge of the ISO 14000 series, indistinct cost–benefit ratio, disruption and high expenses on changing traditional practices, and resistance from employees, etc.; the CIRIA (1999) led a self-completion questionnaire survey of the state of environmental initiatives within the construction industry and of sustainability indicators for the civil engineering industry in the United Kingdom; Tse (2001) conducted an independent questionnaire survey in the Hong Kong construction industry to gain a further understanding of the difficulties in implementing the ISO 14000 series; Lo (2001), also in Hong Kong, made an effort to identify nine critical factors for the implementation of ISO 14001 EMS in the construction industry based on critical factors drawn from an investigation in another industry; the CPSC (2001), in Australia, conducted a questionnaire survey on the New South Wales construction industry on EM with industry leaders; Chen and Li *et al.* (2004b) conducted a questionnaire survey of main contractors in five main cities in mainland China and found that there are five classes of factors influencing the acceptability of the ISO 14000 series of EM standards – governmental regulations, technology conditions, competitive pressures, cooperative attitude, and cost–benefit efficiency; besides this, Zeng *et al.* (2003) also conducted a questionnaire survey on the mainland China construction industry to discover the conditions of implementations of the ISO 14000 series. All these questionnaire surveys aimed to clarify the real situations in the adoption and implementation of the ISO 14000 series of EM standards in the local construction industries, and provided relative perspectives on how to conduct EM to the construction industry.

One important contribution of these surveys is that researchers have obtained useful insights into the problems and difficulties of implementing the ISO 14000 series in construction. Their survey results provide useful information not only for improving efficiency of EMS implementation but also for developing the EMS itself, focusing on highly effective and economical EM in the construction industry. For example, Tse (2001) has found four major obstacles in implementing the ISO 14000 series in the Hong Kong construction industry – lack of government pressure, lack of client requirement or supports, expensive implementation cost, and difficulties in managing the EMS with the current sub-contracting system. One cannot easily draw such constructive conclusions in detail without such a kind of survey.

Besides these questionnaires used to survey the implementation of the ISO 14000 series in the construction industry in different countries, case studies are further applied to investigate the acceptability of the ISO 14000 series to the construction industry. For example, Valdez and Chini (2002) conducted a literature search and a case study of a construction contracting firm certified for the ISO 14001 EMS in the United States. They concluded that the positive aspects of certification outweigh the negative aspects and recommended to add government support and the combined use of the ISO 14000 series with other EM methods and matrices.

On the other hand, the remarkable difference between the rate of ISO 14001 EMS accreditation and EIA implementation in some countries indicates that contractors there have not really implemented EM and accepted the ISO 14000 series (Chen 2003). The EIA of construction projects is a process of identifying, predicting, evaluating, and mitigating the biophysical, social, and other relevant environmental effects of development proposals or projects prior to major decisions being taken and commitments made (IAIA 1997). Although the EIA has been accepted by the construction industry in different countries according to governmental regulations to evaluate the environmental impacts of a construction project, the implementation rate of ISO 14001 EMS accreditation in the construction industry is normally much lower than the implementation rate of EIA. For example, according to the *Official Report on the State of the Environment in China 2001* (China EPB 2002), the annual implementation rate of EIA for construction projects was 97% in 2001 in mainland China. In addition, a further investigation on the implementation rate of EIA in mainland China indicates that the average EIA rate from 1995 to 2001 was 88%, with an increasing rate of 23% (China EPB 2002). By contrast, the percentage of construction enterprises that have been awarded environmental certificates versus total government-registered construction enterprises in mainland China is as low as 0.083% (Chen 2003). Statistical figures also indicate that most construction enterprises have not yet adopted or accepted the ISO 14000 series in mainland China. Because of the disagreement between the implementation rates of EIA and EMS, there may be little coordination between the EIA process and EMS implementation in construction projects, and thus the EIA may not really serve as a tool to promote EM in the construction industry in those countries. For that reason, adverse environmental impacts such as noise, dust, waste, and hazardous emissions still occur frequently in construction projects in spite of their EIA approvals prior to construction.

Besides the status of implementing EIA in construction, the authors also noticed the emerging willingness to apply KM in the construction industry. There is growing consciousness, requirements, and initiatives of KM in order to manage the intellectual capital and get benefits from previous construction processes and projects (Zyngier 2002; Zarli *et al.* 2003). For example, the C-Sand project (c-sand.org.uk) has been conducted in the UK to foster organizational practices which enable knowledge creation for subsequent sharing and re-use, and to promote sustainable construction (Khalfan *et al.* 2003). As one of the largest contracting companies in the United States, Centex Construction Group (centex-construction.com) faces some knowledge-related business challenges that are not always associated with the construction industry. For instance, they have a technology infrastructure in place where all professionals in the company have computing power, i.e. laptops and/or desktops. All offices and job sites are connected to a nationwide WAN via dial, ISDN, and Frame. Remote access is Web-based and available from anywhere to lead some initiatives to increase knowledge sharing and provide better information access across the company's diverse landscape (Velker 1999). Beyond the development of knowledge warehouse (KW) in the construction industry, socio-technical research also reflected that a majority agreed to the statement that KM is an extension of IT (Zyngier 2002). The progress of KM in construction also reflects the trend of construction enterprises away from traditional blue-collar operations towards a more knowledge-based CM.

According to the survey results, the implementation of the EMS requires EM-support approaches as practicable as the EIA approach, which is popular and easier to use by contractors. That is, although the governmental regulations have been identified as a major factor influencing the implementation of the EMS and the EIA in the construction industry according to surveys and case studies mentioned above, the construction industry is still a negative receiver if there are not enough technology conditions to support the implementation of EMS, especially the techniques or tools which can help contractors to conduct EM in construction projects where the most amount of negative environmental impacts are generated. Even for the positive bodies in the construction industry that have high willingness to implement EM, effective, efficient, and economical EM tools are essential. Moreover, the requirements of re-use EM experience also exist (Chen 2003). Based on this consideration, the authors will integrate several EM tools and an EMS-based dynamic EIA process developed previously into an environment of KM entitled E+ for effective, efficient, and economical EM in dynamic construction project management.

6.3 The E+

6.3.1 Methodology

The E+ is an integrative methodology for effective, efficient, and economical EM in construction projects in which an EMS-based dynamic EIA process is applied within a knowledge support system for active knowledge capture and re-use about environmental-conscious CM during construction. The successful implementation of an EMS in construction projects requires far more than just the apparent prevention and reduction of adverse or negative environmental impacts in a new project and its construction process development cycles during pre-construction stage, continuous improvement of the EM function based on institutionalization of change throughout an on-site organization to reduce pollution during construction stage, or efficient synergisms of pollution prevention and reduction such as waste recycle and regeneration during construction and post-construction stages. It necessitates a complete transformation of CM in an environmental-conscious enterprise, such as changes in management philosophy and leadership style, creation of an adaptive organizational structure, adoption of a more progressive organizational culture, revitalization of the relationship between the organization and its customers, and rejuvenation of other organizational functions (such as human resources engineering, research and development, finance, marketing, etc.) (Azani 1999). In addition to the transformation for the EM in construction enterprises, the integrative methodology, E+, for the effective, efficient, and economical implementation of the EM in all phases of the construction cycle including the pre-construction stage, the construction stage and the post-construction stage is necessarily activated, together with other rejuvenated CM functions such as human resources, expert knowledge, and synergetic effect.

There are already some approaches to effectively implementing the EM on site at different construction stages. For example, the CPI approach which is a method to quantatively measure the amount of pollution and hazards generated by a construction process and construction project during construction by indicating the potential level of accumulated pollution and hazards generated from a construction site at the pre-construction stage can be utilized (Chen, Li and Wong *et al.* 2000), and by reducing or mitigating pollution levels during the construction planning stage (Li *et al.* 2002); in addition to the CPI approach, an ANP approach to construction plan selection (Chen and Li *et al.* 2003a,b,c,d), a life-cycle assessment (LCA) approach to material selection (Lippiatt 1999), and a decision programming language (DPL) approach to environmental liability estimation (Jeljeli and Russell 1995) also provide quantitative methods for making decision's on EM at pre-construction stage; for the construction stage, a crew-based IRP approach, which is realized by using bar-code system, can be utilized as an on-site material management system to control and reduce construction waste (Chen and Li *et al.* 2002a); for the post-construction stage, an online waste exchange (Webfill) approach which is further developed into an e-commerce system based on the trip-ticket system for waste disposal in Hong Kong can be utilized to reduce the final amount of C&D waste to be landfilled (disposed of the C&D waste in a landfill) (Chen and Li *et al.* 2002b). Although these approaches to EM in construction projects have proved to be effectively, efficiently, and economically applicable in a corresponding construction stage, it has also been noticed that these EM tools can be further integrated for a total EM purpose in construction projects based on the interrelationships among them. The integration can bring about not only a definite utilization of current EM tools but also an improved environment for contractors to maximize the advantages of utilizing current EM tools due to sharing EM-related data, information, and knowledge in construction project management.

As mentioned earlier, the EMS is not as acceptable as the EIA at present in some countries such as mainland China partly due to the lack of effective, efficient, and economical EM approaches in construction besides the governmental regulations, and the tendency of practical EM in construction is to adopt and implement the EMS when the EIA report/form of a construction project has been approved. As a result, the E+ for contractors to enhance their environmental performance, which integrates all necessary EM tools available currently, is just appropriate.

The proposed E+ aims to provide high levels of insight and understanding regarding the EM issues related to the project management in a construction cycle. In fact, the current EIA process applied in construction projects is mainly conducted prior to the pre-construction stage, when a contractor is required to submit an EIA report/form based on the size and significance of the project and the EIA process for the construction stage is seldom conducted in normalized forms. Due to the strong alterability of the environmental impacts in the construction cycle, commonly encountered static EIA processes prior to construction cannot accommodate the implementation of the EMS in project construction, and a dynamic EIA process is thus designed for the E+. In addition, current EM tools are to be combined with a frame of ISO 14001-required EMS process (a process of the EMS including issuing environmental policies, planning, implementation and operation, checking and corrective action, and management review) (refer to Figure 2.2) according to their interrelationships, with which various EM-related data, information, and knowledge in construction can be captured, organized, and re-used. Because the main task of EM in the construction cycle is to reduce adverse environmental impacts, the dynamic data transference in the framework is the prime focus of the E+ methodology. Thus, a prototype of the E+ is further put forward (refer to Figure 6.1).

Comparing with the original E+ model that was earlier developed in the plain integration of two EM tool entities – E+ Plan entity for environmental-conscious

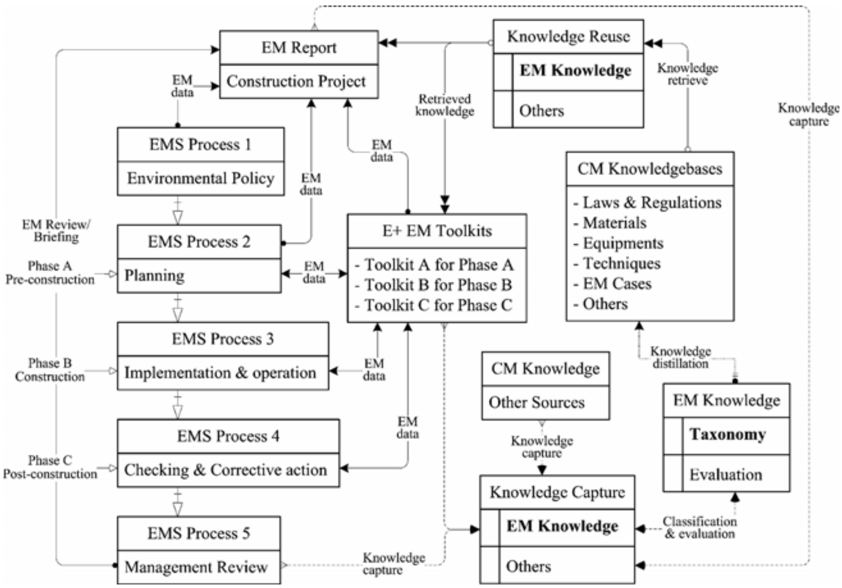


Figure 6.1 The prototype of the E+ model.

planning at pre-construction stage and E+ Logistics entity for implementing EM at both construction stage and post-construction stage with the standard EMS process (Chen *et al.* 2004a) – the E+ prototype being discussed overcomes the limitations in reusing CEM knowledge that exist in the former E+ model by means of an embedded knowledge-driven procedure, and the conceptive E+ prototype is described in Figure 6.1.

The framework of E+ prototype comprises three main sections, including an E+ EM Toolkits entity, an E+ KMS entity, and an EMS-based EIA entity (see Figure 6.1). Features of each entity are described below:

1 The E+ EM Toolkits entity is the core of the E+ prototype, which consists of three kinds of EM tools corresponding to the three phases of a construction cycle – Toolkit A for pre-construction stage, Toolkit B for construction stage, and Toolkit C for post-construction stage.
2 The E+ KMS entity is the knowledge engine of the E+ prototype, which consists of five KM-related subentities: Knowledge Source, Knowledge Capture, Knowledge Classification and Evaluation, Knowledge Storage, and Knowledge Re-use subentities.
3 The EMS-based EIA entity is the essential structural frame of the E+ prototype, which consists of six EMS-related subentities: Environmental Policy, EM Planning, EM Implementation and Operation, EM Assessment,

EM Review, and EM Report subentities. These subentities belong to a standard EMS process normalized by the ISO 14000 series of EM standards.

6.3.2 *Implementation*

The implementation of the E+ prototype in CM needs an integrative software environment in which various E+ entities – the E+ EM Toolkits entity, the E+ KMS entity and the EMS-based EIA entity – can work together with the EMS process to accommodate both intramural and extramural EM-related assessments. Considering the general process of KM comprising knowledge planning, creation, integration, organization, transference, maintenance, and assessment (Rollett 2003) and the general process of computer software development, the authors decided to realize an E+ system through three main steps, as described below:

1 First step: feasibility study. The feasibility study is conducted not only prior to the establishment of the E+ model, but also before system analysis and development of the E+ software environment. First of all, it is important to analyse whether such an E+ system is necessary for the EMS-based dynamic EIA process in project construction, and this is to be done prior to the establishment of the E+ model. Next, if the E+ system is necessary, it requires a search for enough quantitative EM tools to support the E+ system, and this is to be done before system analysis and development of the E+ system. The feasibility study is essential for both a practicable E+ prototype and an effective, efficient, and economical E+ system.
2 Second step: system analysis and realization. System analysis and realization are to be conducted after the E+ model has been established. The aim of this step is to transform the E+ system from a model to a software environment with computer programming. Constrained by the length of this chapter, no further discussion is presented here to illustrate the development of the E+ system.
3 Third step: system evaluation. System evaluation is a trial process for the developed E+ system. There is also no further discussion related to this step as the E+ system is under construction. However, an experimental case study is conducted below to demonstrate the effective, efficient, and economical EM function of the E+ system.

The following discussions focus on several core EM tools adopted in the E+ model, and interrelationships among these EM tools while working for the EMS-based dynamic EIA process. As the EM tools selected for the E+ model in this chapter are the CPI approach to indicate adverse environmental impacts at pre-construction stage, the IRP approach for material management on site at construction stage, and Webfill approach for residual and waste material and equipment exchange at post-construction stage, no more EM tools are discussed here.

6.4 EM tools for the E+

6.4.1 CPI

In the prototype of the E+, the CPI approach is set to the E+ EM Toolkit A for construction planning at pre-construction stage (refer to Figure 6.1). The E+ EM Toolkit A captures data from three kinds of sources:

1. Source one: EMS Process, including EMS Processes 2 and 3.
2. Source two: E+ EM Toolkits, including Toolkits B and C.
3. Source three: knowledge bases (KBs) of EM, including knowledge base of environmental law and regulation, environmental-friendly construction materials, environmental-friendly construction machines, environmental-friendly construction techniques, EM cases, etc.

Meanwhile, the E+ EM Toolkit A transfers data to these three kinds of data sources, and to the EM report such as the dynamic EIA report of a construction project.

A quantitative approach named construction pollution index (CPI) (refer to Chapter 3) is adapted in the E+ EM Toolkit A to evaluate adverse environmental impacts in construction planning at pre-construction stage. The CPI is an approach to quantitatively measure the amount of pollution and hazards that will be generated by a construction project or a construction process during construction. The method measures CPI as shown in Equation 6.1.

$$\mathrm{CPI} = \sum_{i=1}^{n} \mathrm{CPI}_i = \sum_{i=1}^{n} h_i \times D_i \tag{6.1}$$

where CPI is Construction pollution index of an urban construction project; CPI_i is Construction pollution index of a specific construction operation i; h_i is hazard magnitude per unit of time generated by a specific construction operation i; D_i is duration of the construction operation i that generates hazard h_i; and n is number of construction operations that generate pollution and hazards.

In Equation 6.1, parameter h_i is a relative value indicating the magnitude of hazard generated by a particular construction operation in a unit of time. Its value is normalized into the range [0, 1]. If $h_i = 1$, it means that the hazard can cause fatal damage or be catastrophic to people and/or properties nearby. For example, if a construction operation generates noise and the sound level at the receiving end exceeds the “threshold of pain”, which is 140 dB (McMullan 1998) then the value of h_i for this particular construction operation is 1. If $h_i = 0$, then it indicates that no pollution and hazard is detectable from a construction operation. It is possible to identify values of h_i for all types of pollution and hazards generated by commonly used construction operations and methods based on users' experience and expert opinions.

Because the value of CPI reflects the accumulated amount of adverse environmental impacts generated by a construction project within its project duration, its utilization in construction planning is easily realized though a CPI histogram, similar to the resource histogram in a Gantt chart which is used in construction scheduling. By integrating the concept of CPI into a commonly used tool for construction project management such as Microsoft Project©, a system to neatly combine EM with project management is then formed, and project managers can use the CPI histogram to identify the periods in which the project will generate the highest amount of pollution and hazards, and reschedule the whole project to level extremely high CPI (refer to Chapter 3).

However, with respect to further reusing CM knowledge to define the CPI_i (CPI of a specific construction operation i) for each process in different construction projects, the authors noticed that experts' opinions varied from project to project regarding the value of CPI_i. This means that the topic of reusable CM knowledge to define the current experience-based CPI_i in construction planning has aroused discussion, and therefore the development of a new tool to suit the computation of CPI to facilitate the re-use of experts' knowledge at pre-construction stage is required. The tool for CM knowledge re-use to define CPI_i is developed by using artificial neural network (ANN) approach. As the ANN-based approach to define CPI_i has already been discussed in previous works (Chen and Li *et al.* 2004a,b), it is just adopted in the E+ prototype as an EM tool in the E+ EM Toolkit A.

6.4.2 IRP

In the prototype of the E+, the IRP approach (refer to Chapter 4) is set to the E+ EM Toolkit B for construction at construction stage (refer to Figure 6.1). The E+ EM Toolkit B captures data from three kinds of sources:

1. Source one: EMS Process 3.
2. Source two: E+ EM Toolkits, including Toolkits A and C.
3. Source three: KBs of EM, including knowledge base of environmental law and regulation, environmental-friendly construction materials, environmental-friendly construction machines, environmental-friendly construction techniques, and EM cases.

Meanwhile, the E+ EM Toolkit B transfers data to these three kinds of data sources, and to the EM report such as EIA report of a construction project.

The IRP approach (refer to Chapter 4) is an approach to quantatively measure the amount of material waste generated by a construction project or a process during construction. IRP measures the exact amount of material saved or wasted by each crew during construction, as shown in Equation 6.2.

$$C^i(j) = \sum_n \Delta Q^i(j) \times P_i = \sum_n \left\{ Q^i_{\text{es}}(j) - \left[Q^i_{\text{de}}(j) - Q^i_{\text{re}}(j) \right] \right\} \times P_i \tag{6.2}$$

where $C^i(j)$ is the total amount of material i saved (if $C^i(j)$ is positive) or wasted (if $C^i(j)$ is negative) by crew j; $\Delta Q^i(j)$ is the extra amount of material i saved (if the amount is a positive value) or wasted (if the amount is a negative value) by crew j; $Q^i_{\text{es}}(j)$ is the estimated quantity that includes the statistic amount of normal wastage; $Q^i_{\text{de}}(j)$ is the total quantity of material i requested by crew j; $Q^i_{\text{re}}(j)$ is the quantity of unused construction materials returned to the storage by crew j; P_i is the unit price for material i; and n is the total number of tasks in the project that need to use material i.

According to the Equation 6.2, for a particular type of material i, the performance of crew j in terms of material wastage can be measured by $\Delta Q^i(j)$, and at the end of the project, the overall performance of crew j can be rewarded in agreement with $C^i(j)$. That is, the IRP is implemented according to the amount of materials saved or wasted by a crew, i.e. if a crew saves materials ($\Delta Q^i(j) > 0$), the crew will be rewarded based on the quantity of $C^i(j)$.

As the computation of IRP is done by measuring the exact amount of material saved or wasted during the construction process and comparing it with the estimated quantity of materials that will probably be consumed based on the statistic amount of normal wastage in other construction processes (see Equation 6.2), there is also a space to re-use CM knowledge to define the value of $Q_i(j)_{\text{es}}$. As the adoption of the ANN approach in quantity survey (Adeli and Karim 2001) for CM retrieval and re-use has received wide recognition in construction, the authors of further employed another ANN model (Chen *et al.* 2004a,b) to support knowledge re-use in IRP computation in the E+ prototype.

6.4.3 Webfill

In the prototype of the E+, the Webfill approach (refer to Chapter 5) is set to the E+ EM Toolkit C for post-construction work at post-construction stage (refer to Figure 6.1). The E+ EM Toolkit C captures data from three kinds of sources:

1 Source one: EMS Process 4.
2 Source two: E+ EM Toolkit B.
3 Source three: KBs of EM, including knowledge base of environmental laws and regulations, environmental-friendly construction materials, environmental-friendly construction machines, environmental-friendly construction techniques, and EM cases.

Meanwhile, the E+ EM Toolkit C transfers data to these three kinds of data sources, and to the EM report such as the dynamic EIA report of a construction project.

The Webfill approach (refer to Chapter 5) is an e-commerce method to increase the amount of C&D waste exchanged for re-use and recycle among different construction sites and material-regeneration manufactories. Disposal of C&D waste to landfills is usually charged in many countries (Chen 2003). For example, in order to orderly dispose C&D waste to disposal facilities by trucks, the TTS was implemented in the Hong Kong construction industry in 1999, which requires contractors to pay for the disposal of their C&D waste in terms of waste disposal receipts issued to them. The Webfill approach sets the TTS-based e-commerce model conforming to the external requirement, and simulation results indicate that the Webfill-enhanced TTS can apparently reduce the total amount of C&D waste through encouraging the increase of waste re-use and recycle.

The trade promotions of the Webfill system include an annual reward system and a finite release of commission fee based on the trading records of each member. Two kinds of EM-related data, which the Webfill system provides based on its trading records, can be used to indicate the environmental-conscious performance of contractors. They are the quantity of C&D waste a contractor sold (Q_{sold}) and the quantity of regenerated materials or reusable material a contractor bought (Q_{bought}). By using these two kinds of EM-related data, Equation 6.2 can be further developed into Equation 6.3. According to Equation 6.3, if the waste generated by crew j is sold through the Webfill system or the crew j request regenerated material bought from the Webfill system, the crew can thus be rewarded.

$$C^i(j) = \sum_n \Delta Q^i(j) \times P_i = \sum_n \{[Q^i_{\text{es}}(j) - (Q^i_{\text{de}}(j) - Q^i_{\text{re}}(j))] + Q^i_{\text{sold}}(j) + Q^i_{\text{bought}}(j)\} \times P_i \tag{6.3}$$

where $Q^i_{\text{sold}}(j)$ is the quantity of waste material i sold by or related with crew j; and $Q^i_{\text{bought}}(j)$ is the quantity of regenerated material i requested by crew j.

The Webfill in the E+ EM Toolkit C plays a supporting role in CM knowledge retrieval and re-use by providing statistic data to define the value of $Q_i(j)_{\text{es}}$ required in both Equations 6.2 and 6.3. All statistic data from Webfill can be further used for the ANN model too.

6.4.4 *Interrelationships*

The interrelationships among the EMS process, the EIA process, the EM Toolkit, and the *Knowledge Capture* process and *Knowledge Re-use* process can be put up in agreement with EM-related data transferences. There are six kinds of EM-related data transferences in the E+ system. The first kind of data transference occurs between the EMS process and the EIA process; the second kind of data transference occurs among the EM Toolkits and the EIA process; the third kind of data transference occurs among the various EM Toolkits; the fourth kind of data transference occurs from the Knowledge Re-use entity to the EM

Toolkits and the EIA process; the fifth kind of data transference occurs from the EM Toolkits, the EIA process and the EMS process to the *Knowledge Capture* entity; and the sixth kind of data transference occurs from *Knowledge Capture* entity to the *Knowledge Re-use* entity through several essential KBs such as KB of environmental law and regulation, KB of environmental-friendly construction materials, KB of environmental-friendly construction machines, KB of environmental-friendly construction techniques, and KB of EM cases, etc. Because all these data are generated from different construction stages, integrative data transference in the E+ system can thus provide up-to-date information to the EIA process and the dynamic EIA process is realized accordingly. In order to completely clarify the interrelationships potentially existing in the E+ system, some of the EM-related data and their transferences are summarized in Table 6.1.

For the knowledge-driven E+ system, a proper way of representing EM-related knowledge is essential to influence its effectiveness. Knowledge representation, as one of the central and in some ways most familiar concepts in artificial intelligence, is best understood in terms of the five fundamental roles that it

Table 6.1 Interrelationships among EM-related data in the E+ system

Data host	*Data name*	*Transfer to*	*Received from*	*Usefulness*
CPI host (Toolkit A)	CPI CPI_i	EIA host, KBs	–	Data update for EIA report
	CPI_i	EMS process②, KBs	–	Construction planning
	CPI_{waste}	IRP host	–	Quantity survey of waste
	h_i	KBs	KBs	Hazard magnitudes
	D_i	KBs	KBs	Construction duration
	$\Delta Q^i(j)$	–	IRP host, KBs	Wastage rate survey
	Q_{sold}, Q_{bought}	–	Webfill host, KBs	Wastage rate survey
	undefined	–	EMS process③ and⑤	Pollution and hazard survey
IRP host (Toolkit B)	$\Delta Q^j(j)$	CPI host, KBs	–	Wastage rate
	$\Delta Q^i(j), C^i(j)$	EMS process③, KBs	–	Reward
	$\Delta Q^i(j)$	Webfill host, KBs	–	Quantity survey of waste
	CPI_{waste}	–	CPI host, KBs	Wastage rate
	$Q^i_{de}(j), Q^i_{re}(J)$	–	EMS process③ and④, KBs	Quantity survey of waste
	Q_{sold}, Q_{bought}	–	Webfill host, KBs	Quantity survey of waste

Table 6.1 (Continued)

Data host	*Data name*	*Transfer to*	*Received from*	*Usefulness*
Webfill host (Toolkit C)	Q_{sold}, Q_{bought}	IRP host, KBs	–	Quantity survey of waste
	Q_{sold}	EMS process④, KBs	–	Quantity survey of waste
	Q_{bought}	EMS process③, KBs	–	Deliver to crews
	Q_{sold}, Q_{bought}	CPI host, KBs	–	CPI_{waste}
	Undefined	–	IRP host, KBs	Waste for exchange
	Undefined	–	EMS process④, KBs	Price of waste
EIA host	CPI, CPI_i	–	CPI host, KBs	Data update for EIA report
	$\Delta Q^i(j)$	–	IPR host, KBs	Data update for EIA report
	Q_{sold}, Q_{bought}	–	Webfill host, KBs	Data update for EIA report
	Undefined	–	EMS process①, KBs	Data update for EIA report
	Undefined	–	EMS process②, KBs	Data update for EIA report

Note
CPI_{waste} represents the CPI_i that involves waste impact only.

plays as a surrogate, a set of ontological commitments, a fragmentary theory of intelligent reasoning, a medium for efficient computation, and a medium of human expression (Davis *et al.* 1993). Leaving the conceptive discussions on the knowledge representation aside, the authors adopt two formats of CM knowledge to power the operation of the E+ system. They are the CPI_i for the E+ EM Toolkit A and the $Q_i(j)_{es}$ for the E+ EM Toolkits B and C, which are the stochastic functions of several characters of construction processes (Chen and Li *et al.* 2004a,b). According to the definitions of the CPI_i and the $Q_i(j)_{es}$, their values are computed by using statistic data and extracted by using ANN approach.

6.5 Experimental case studies

The experimental case studies conducted here combine data such as wastage at different construction stages (Vaid and Tanna 1997) from several separate cases (Chen and Li *et al.* 2000/4) and authors' experiences with a virtual construction project because there is no such construction project currently that has mature experience regarding the application of the E+ system as well as the inavailability of data at present to demonstrate the utilization of the E+ system from only one construction project. In this case, the aim of these experimental case studies focuses mainly on the utilization of the E+ model, and data adopted are for references only although there are practical backgrounds to support them. Therefore, it is necessary to note that as the prime objective of this case study is to demonstrate the usefulness of the E+ prototype, the authenticity of data adopted is de-emphasized. Case studies for real construction projects can be further conducted in the future when the E+ software environment has been realized.

6.5.1 Case study A

The experimental case study A presented in Table 6.2 demonstrates the process of the E+ model. The process of the EMS-based dynamic EIA in the experimental case study is divided into three stages corresponding to the construction cycle comprising pre-construction stage, construction stage, and post-construction stage (refer to Table 6.2). The EM-related data for the EMS-based dynamic EIA provided by the E+ system are different from stage to stage. At the pre-construction stage, there are two kinds of data for the EIA – the original set of CPI_i and the Q_{bought} requested by each crew; at the construction stage, there are four kinds of data for the EIA – the relay set of CPI_i, the $\Delta Q^i(j)$, the Q_{sold}, and the Q_{bought}; and at the post-construction stage, there are three kinds of data for the EIA – a final set of CPI_i, a total Q_{sold}, and a total Q_{bought}. The functions of current EM tools integrated in the E+ model are different, for example, the CPI approach deals with total adverse environmental impacts of construction processes, while the IRP approach and the Webfill approach deal with the C&D waste only, therefore the CPI_i in this case study is thus represented by a CPI_{waste} which represents the CPI_i that involves waste impact only (refer to Table 6.1 and Equation 6.1).

Moreover, this experimental case study puts forward and utilizes the concepts of original CPI_{waste}, relay CPI_{waste}, and final CPI_{waste} to demonstrate the process of the EMS-based dynamic EIA, and considers these three kinds of CPI an essential data in an EIA report. The original CPI_{waste} means the CPI_{waste} that is valued before a construction process, the relay CPI_{waste} means the CPI_{waste} that is devalued during a construction process, and the final CPI_{waste} means the CPI_{waste} that is finally valued after a construction process. Because the value of the CPI_{waste} is regarded as an important data in an EMS-based EIA process, the changing process of the three kinds of CPI_{waste} appropriately incarnates or reflects the process of a dynamic EIA. Thus an EMS-based dynamic EIA process is realized.

It is important to note that in order to value each CPI_{waste}, experts' experiences have to be used to set the magnitude of h_i corresponding to changed amounts of Q_{sold} and Q_{bought}. The expert experiences required to set h_i are stored in the

Table 6.2 The E+ implementation for a dynamic EIA in a construction cycle: case study A

Construction tasks	*Duration (day)*	*EIA data at different construction stages*								
		Pre-construction		*Construction*				*Post-construction*		
		Original CPI_{waste}	Q_{bought} *(ton)*	*Relay* CPI_{waste}	$\Delta Q^i(j)$ *(ton)*	Q_{sold} *(ton)*	Q_{bought} *(ton)*	*Final* CPI_{waste}	*Total* Q_{sold} *(ton)*	*Total* Q_{bought} *(ton)*
Caisson pile	31	0.07	0.0	0.05	0.1	0.1	0.0	0.05	0.1	0.0
Braced excavation	57	0.13	0.0	0.15	0.5	0.3	0.0	0.10	0.5	0.0
Transportation	435	0.00	0.0	0.05	0.0	0.0	0.0	0.05	0.0	0.0
Support system – building	42	0.10	22.6	0.12	1.2	0.2	5.5	0.10	0.6	28.1
Support system – demolition	28	0.60	0.0	0.50	0.0	2.1	10.0	0.45	20.5	10.0
Foundation construction	43	0.10	0.1	0.20	3.3	3.2	1.1	0.18	5.6	1.2
Structural RC work – rebar	155	0.06	3.2	0.05	1.5	5.5	1.8	0.04	6.0	5.0
Structural work – form	155	0.36	5.7	0.30	1.2	0.2	1.1	0.28	0.5	6.8
Structural work – concrete	156	0.05	0.0	0.03	3.1	5.1	0.0	0.02	5.1	0.0
Mansion work	176	0.20	0.5	0.10	5.6	3.3	2.3	0.09	3.5	2.8
Structural steel	94	0.10	0.0	0.01	0.5	0.0	0.0	0.01	0.0	0.0
Finish work – wall	211	0.29	0.0	0.18	2.5	3.6	0.0	0.16	3.6	0.0
Finish work – ceiling	211	0.39	0.0	0.26	3.2	5.5	0.0	0.25	5.5	0.0
Finish work – floor	181	0.12	0.0	0.08	1.7	2.1	3.0	0.07	2.1	3.0
Total		2.57	32.1	2.08		31.2	24.8	1.85	53.6	56.9

Knowledge Re-use entity which is distilled from crude data in KBs including KB of environmental law and regulation, KB of environmental-friendly construction materials, KB of environmental-friendly construction machines, KB of environmental-friendly construction techniques, and KB of EM cases, etc. Therefore the EM-related construction knowledge effectively supports the process of EMS-based dynamic EIA.

The result of case study A indicates that the implementation of the E+ system can finally reduce the adverse environmental impacts of a construction project. For example, the total value of original CPI_{waste} of all construction tasks in the experimental case study is 2.57, that of relay CPI_{waste} is 2.08, and that of final CPI_{waste} is 1.85. That is, the E+ system draws support from several EM tools such as the CPI approach, the IRP approach and the Webfill approach, and realizes an EMS-based dynamic EIA process, where the benefits of various EM tools can be shared within the E+ environment through EM-related data transfer and integrated data, information, and knowledge utilization.

6.5.2 *Case study B*

Being summarized in Table 6.3 and Figures 6.2 and 6.3, the experimental case study B demonstrates operation profiles of the E+ prototype by using quantified knowledge of each variable such as the CPI_i and the $Q_i(j)_{es}$ etc. in correspondence with the re-use of CM knowledge for a dynamic EIA process in the construction lifecycle of a project. In addition to the CPI_i and the $Q_i(j)_{es}$, a concept of CPI of C&D waste (denoted as $CPI_{i,waste}$ [CPI of waste of a specific construction operation i]) is introduced as a necessary complement of the CPI to each specific construction operation i and a construction project. The authors further utilize the parameters of original $CPI_{i,waste}$, relay $CPI_{i,waste}$, and final $CPI_{i,waste}$ to demonstrate the process of the dynamic EIA in a construction lifecycle for evaluating the adverse environmental impacts of C&D waste, in parallel with a series of total CPI parameters including original CPI_i, relay CPI_i, and final CPI_i. The original $CPI_i/CPI_{i,waste}$ represents the $CPI_i/CPI_{i,waste}$ that is valued prior to a construction process for construction planning, the relay $CPI_i/CPI_{i,waste}$ denotes the $CPI_i/CPI_{i,waste}$ that is revalued during a construction process for construction pollution control, and the final $CPI_i/CPI_{i,waste}$ refers to the $CPI_i/CPI_{i,waste}$ that is finally valued after a construction process for knowledge re-use. Because the value of CPI is regarded as one important data in an EIA process, the changing process of the $CPI_i/CPI_{i,waste}$ can therefore reflect the dynamic alteration process of EIA/EM, which is enabled by the E+ system, and these two series of CPI values can be further used in an EM report and new construction projects.

It is necessary to note that in order to value the $CPI_i/CPI_{i,waste}$ of each construction process, experts' experiences have to be used according to the changed quantities of the $Q_i(j)_{es}$, the $Q_i(j)_{sd}$, and the $Q_i(j)_{bt}$, as well as the changed quantities of energy consumption. The expert experiences required to define the $CPI_i/CPI_{i,waste}$ are stored in the Knowledge Re-use entity, and are distilled from

Table 6.3 The E+ operation for a dynamic EIA process in a project construction lifecycle: case study B

Construction process	Stage	*Pre-construction*				*Construction*					*Post-construction*				
	Duration (day)	*Original CPI_i (per day)*	*Original $CPI_{i,waste}$ (per day)*	$Q_i(j)_{es}$ (ton/m^2)	$Q_i(j)_{bought}$ (ton/m^2)	*Relay CPI_i (per day)*	*Relay $CPI_{i,waste}$ (per day)*	$\Delta Q_i(j)$ (ton/m^2)	$Q_i(j)_{sold}$ (ton/m^2)	$Q_i(j)_{bought}$ (ton/m^2)	*Final CPI_i (per day)*	*Final $CPI_{i,waste}$ (per day)*	*Revised $Q_i(j)_{es}$ (ton/m^2)*	*Final $Q_i(j)_{sold}$ (ton/m^2)*	*Final $Q_i(j)_{bought}$ (ton/m^2)*
RC caisson pile	31	0.65	0.07	7.60	0.00	0.60	0.05	0.02	0.01	0.00	0.60	0.05	7.57	0.01	0.00
RC braced excavation	57	0.20	0.13	3.80	0.00	0.35	0.15	0.03	0.01	0.00	0.30	0.10	3.76	0.01	0.00
Transportation	435	0.35	0.00	N/A	N/A	0.45	0.05	N/A	N/A	N/A	0.45	0.05	0.00	N/A	0.00
Support system – building	42	0.25	0.10	0.80	0.20	0.30	0.12	0.01	0.00	0.20	0.30	0.10	0.39	0.00	0.40
Support system – demolition	28	0.85	0.60	N/A	0.00	0.80	0.50	0.00	1.20	0.00	0.80	0.45	N/A	1.25	0.00
RC foundation construction	43	0.25	0.10	3.10	0.10	0.45	0.20	0.02	0.01	0.02	0.45	0.18	2.95	0.01	0.12
Structural RC work – rebar	155	0.15	0.06	0.60	0.60	0.15	0.05	0.01	0.01	0.02	0.15	0.04	−0.04	0.01	0.62
Structural RC work – form	155	0.45	0.36	0.50	0.20	0.40	0.30	0.01	0.00	0.10	0.40	0.28	0.19	0.01	0.30
Structural RC work – concrete	156	0.65	0.05	0.60	0.00	0.60	0.03	0.01	0.01	0.00	0.60	0.02	0.58	0.01	0.00
Concrete masonry work	176	0.25	0.20	0.80	0.20	0.15	0.10	0.01	0.01	0.02	0.15	0.09	0.56	0.01	0.22
Structural steel framework	94	0.10	0.10	0.30	0.00	0.10	0.01	0.01	0.01	0.00	0.10	0.01	0.28	0.01	0.00
Finish work – wall mortar	211	0.35	0.29	0.10	0.00	0.25	0.18	0.01	0.01	0.00	0.25	0.16	0.08	0.01	0.00
Finish work – ceiling mortar	211	0.45	0.39	0.10	0.00	0.35	0.26	0.01	0.01	0.00	0.35	0.25	0.08	0.01	0.00
Finish work – floor mortar	181	0.25	0.12	0.10	0.00	0.15	0.08	0.01	0.01	0.01	0.15	0.07	0.07	0.01	0.01
Total		5.20	2.57	18.40	1.30	5.10	2.08	0.16	1.30	0.37	5.05	1.85	15.27	1.36	1.67

Notes

CPI charts – refer to Figures 6.2 and 6.3.

1 The values of $Q_i(j)_{es}$, $Q_i(j)_{bought}$, and $Q_i(j)_{sold}$ are converted by using the quantities of various materials in each construction process.

2 The unit of area (m^2) is based on the plot area of the building.

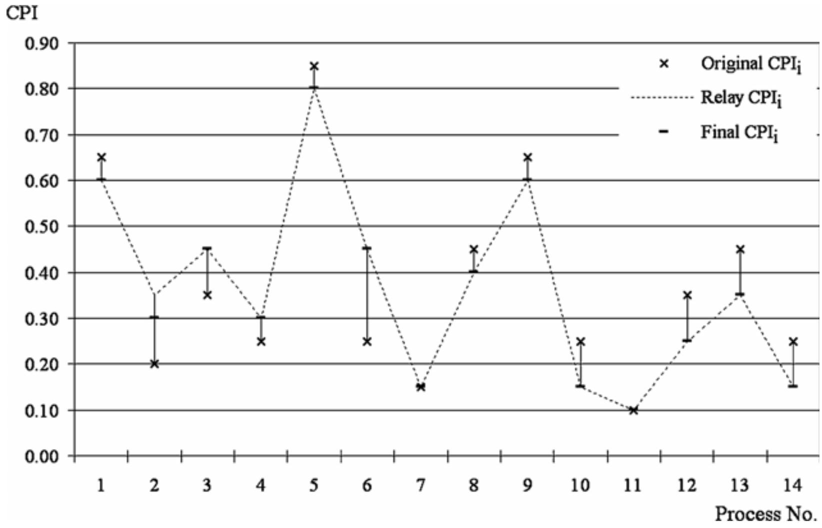


Figure 6.2 CPI chart: case study B.

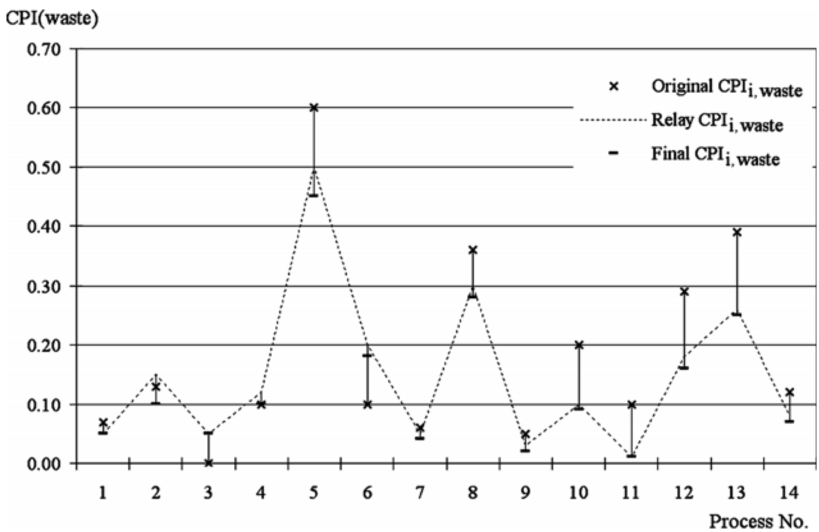


Figure 6.3 CPI_{waste} chart: case study B.

raw information in knowledge warehouse including knowledgebase of environmental law and regulation, knowledgebase of materials, equipment, techniques, and EM cases, etc. All these procedures can finally effectively power the process of knowledge-driven EMS-based dynamic EIA by reusing EM-related construction knowledge.

The result of this experimental case study indicates that the implementation of the E+ system can finally reduce the adverse environmental impacts due to construction. For example, the total value of original $CPI_i/CPI_{i,\text{waste}}$ of all construction tasks is 5.20/2.57, the total value of relay $CPI_i/CPI_{i,\text{waste}}$ of all construction tasks is 5.10/2.08, and the total value of final $CPI_i/CPI_{i,\text{waste}}$ of all construction tasks is 5.05/1.85; and there is a 3% reduction of CPI while there is a 28% reduction of CPI_{waste}. Further to the reductions to the $CPI_i/CPI_{i,\text{waste}}$, the authors provide two CPI charts (Figures 6.2 and 6.3), which can be used to explain and analyse the changing process and the alterations of the $CPI_i/CPI_{i,\text{waste}}$ in each construction process. By using these results, the authors believe that the operation of the E+ system can not only provide an integrated computer tool to facilitate the implementation of a knowledge-driven EMS in construction projects but also create a decision-making environment to support further analysis relating to the reduction of adverse environmental impacts due to construction.

According to the results from case study B, it finally appears to the authors that the E+ system can draw support from several mature EM tools such as the CPI approach, the IRP approach, the Webfill approach, etc. and further realize a knowledge-driven EMS-based dynamic EIA process, while the benefits of various EM tools can be shared within an E+ system and EM-related data transference and integrated data, information, and knowledge utilization can be realized.

6.6 Future trends

Recommendations on the integrative knowledge management system for environmental-conscious construction come from the usefulness, efficiency, and benefit of the E+ prototype and EM tools, which have been demonstrated in this chapter. However, due to the limitations of current research, it is recommended to conduct further research on both the development of the E+ software environment and the development of more effective, efficient, and economical EM tools for the E+ system.

First of all, the E+ model can be further developed to a Web-based environmental information and knowledge management system for contractors to implement EM in construction project management. According to the essential theory and practice of EM in construction, environmental information is required in construction planning, construction material management, C&D waste exchange, etc., whilst EM knowledge in construction is essential to support decision-making by using various EM tools. Because both environmental information and EM knowledge are needed in the E+ system and the Internet is particularly suitable to implement effective and flexible CM by mobile site management units, the key issues in the development of such an E+ system are how to establish a Web-based software system and enable managers in different construction sites to use and share environmental information and knowledge on the same platform of E+, and how to capture, transfer, and re-use necessary data between the E+ system and current CM system. Moreover, additional functional components such as E+ EIA besides the E+ Toolkits are also under consideration.

Besides the development of the E+ system, further researches are also required in the development of fully user-oriented EM tools and their integration in the E+ system. The fully user-oriented EM tools can enable contractors or construction managers to use the EM toolkits easily by themselves without the help of tool developers. For example, the fully user-oriented tool of CPI can enable them to define the CPI of each construction process in a construction plan and then level the extremly high CPI, whilst the fully user-oriented tool of env.Plan (chen 2003) can enable them to transfer necessary data from construction plan alternatives to an ANP environment and thus to select the most environmental-friendly construction plan. In addition to the development of the fully user-oriented EM tools, improvements on the functionally different approaches for EM in construction focusing on the innovation of these approaches are also necessary. For example, the CPI of a construction process is defined by experts' experience currently, and this treatment is definitely practicable; however, in order to receive a wide recognition and minimize the arbitrary decision or subjective error on the definition of the CPI of each construction process, it is suggested to develop an objective calculation method to define the CPI of each possible construction process a contractor may use in construction planning. So both the development of the fully user-oriented EM tools and the consummation of current functionally different approaches for EM in construction are required in further researches.

Beyond the consummation of the E+ system and its components, additional functionally different approaches for EM in construction are also necessarily to be developed in order to improve the performance of the E+ system. Currently, the potential functionally different approaches to implementation of EM in construction include life-cycle analytical (LCA) approach and risk analytical approach for E+ EM Toolkit A, EIA template for new E+ EIA Toolkit, etc.

Although this research project has been accomplished with satisfied results, there are some limitations not only within the research but also in the duplicate implementation of the EM tools developed in the research. The limitations of the research exist in the following two areas:

- This research has not accomplished an E+ software environment to further demonstrate its usefulness, and efficiency in EM in construction.
- The CPI method has not been developed into a fully user-oriented tool that can help contractors to deal with any CPI problem in construction planning.

As a conclusion, it is recommended that further research and development for the E+ system focus on the development of a Web-based E+ system, the consummation and innovation of current EM tools in construction, and the development of new EM approaches for the E+ system.

6.7 Conclusions

This chapter presents a research for an integrative methodology named E+ for EMS-based dynamic EIA in construction, which integrates various EM approaches with a general EMS process throughout all construction stages in a construction project. The EM approaches integrated in the E+ are divided into three categories: EM Toolkit A for pre-construction, EM Toolkit B for construction, and EM Toolkit C for post-construction. These EM Toolkits are further integrated with ISO 14001 EMS and EM Knowledge Capture and Re-use entities for an integrative knowledge management system for environmental-conscious construction. In addition to the proposed E+ prototype, an experimental case study has also been conducted to demonstrate the usefulness and efficiency of the E+ system. The E+ is expected to effectively, efficiently, and economically assist contractors to enhance their EM techniques and environmental performances in construction project management, and to overcome the weakness of static EIA, formally applied in the construction industry in some countries, by the dynamic EIA process, where the necessary data for an EIA report can be updated in the construction cycle.

Regarding the integrative methodology of knowledge management system for EM in construction, this chapter mainly contributes to existing theory for EM in construction in the area of quantitative analytical approaches and their integrative implementation. According to the literature review and questionnaire survey for this research, the lack of an effective, efficient, and economical quantitative analytical approach is one of the obstacles to implementing EM in construction. Therefore, there are four points of contributions from this research to the existing theory or practice for EM in construction:

- This research has developed an integrative methodology (E+) for implementing EMS and knowledge management in construction, with a rigorous dynamic EIA model based on various functionally different approaches to EM in a construction cycle. The E+ prototype is originally created in both theory and practice for EM in construction, and it is open to further integration of various functionally different approaches for EM in construction other than the three EM tools presented in this chapter. Because the E+ is both EMS-oriented and process-oriented in construction, it can help contractors to implement EM from a messy situation to a normal system and to effectively share EM knowledge and information internally and externally.
- The CPI method integrated in the E+ model is a quantitative approach to predicting and levelling complex adverse environmental impacts potentially

generated from construction and transportation due to the implementation of a construction plan. As a result, the CPI method has been integrated into E+ EM Toolkit A, one functional section of E+ system, to carry out the task in environmental-conscious construction planning.

- The IRP method is a quantitative approach to reduce wastage of construction materials on a construction site, and it is designed to be effectively implemented by using a bar-code system. The IRP is then integrated in the E+ EM Toolkit B, another functional section of E+, as a basic component.
- The Webfill method is an e-commerce model designed for the trip-ticket system to effectively reduce, re-use, and recycle C&D waste. Although there is lack of data to prove the efficiency in reality, the computer simulation results, and a questionnaire survey from another research (Chen 2003) have proved that the Webfill system can effectively realize the design function. As a result, the Webfill is also integrated in the E+ model as an important component of the E+ EM Toolkit C.

Although the software environment of the E+ has not been presented in this chapter, the demonstration of the E+ system in the experimental case study enabled a closer understanding of how the E+ system can be effectively applied for EM in construction, and it also unveiled that the E+ methodology is flexible in the integrative implementation of functionally different quantitative approaches to EM in construction. In order to promote the implementation of the E+ model, further research is required to transfer the E+ model to a computer software environment and improve current EM tools and develop more EM approaches as subsidiary components of the E+ system to deal with all adverse environmental impacts of construction for total EM in construction project management.

Appendix A

A questionnaire about EMS application

A.1 A covering letter

March 31, 2001

Subject: A questionnaire on the adoption and implementation of the ISO 14000 series of standards and environmental management systems in construction enterprises in mainland China.

Dear Sir or Madam,

I am a PhD candidate in the department of Building and Real Estate in the Hong Kong Polytechnic University, and I am studying on environmental management in construction projects in China. I submit this questionnaire to you personally, and I will appreciate your attention, cooperation, response, and comments.

Ever since the ISO 14000 series was introduced in 1996, more and more attention has been paid to environmental management system in construction industry globally, and has become the hot spot in construction management since the ISO 9000 series introduced in 1992. In Hong Kong, there are already 21 construction companies who have obtained ISO 14001 EMS certificates by the end of March 2001. We believe that more and more construction companies in the mainland of China will adopt and implement EMS, including the ISO 14000 series EMS, for their sustainable development in a society where environment is a concern. The aim of this questionnaire survey is to find out the degree of self-identification with the ISO 14000 series and EMS in some large-scale construction companies in selected cities of mainland China. The results of this survey can provide valuable data to my research and dissertation – quantitative analytical approach for environmental management in construction projects.

Your comprehension and sustentation are great affirmation and assistance to my research! I frankly assure that all information about your company you provide in this questionnaire survey will only be used in statistical analysis in this learning research, and I will never open any individual information to the public. Kindly take time to complete this questionnaire, and try to send it back to me as soon as possible.

Please leave your contact information at the end of this questionnaire if you want to see the report of this survey. I will send the entire survey report to you later. In case you have no time to do this survey, could you please transfer this questionnaire to your reliable colleagues? If it is possible, could you please pass on this questionnaire to more colleagues of yours? I am now in Chengdu, and will go back to Hong Kong in August. Please call me at 028-5572374 during these days for anything I should do.

Thank you very much for your comprehension, assistance, and support!

Sincerely yours,

(Signature)
Zhen Chen
PhD Candidate
Address:
TU410, Department of Building and Real Estate
The Hong Kong Polytechnic University, Hong Kong
Tel: 852-27665873, Fax: 852-27645131
E-mail: z.chen@polyu.edu.hk
URL: http://hk.geocities.com/at55379/index.html

A.2 Questionnaire

Part 1 Background (Please check all that applies)

1.1 Major source of construction projects for your company:

- ☐ Governmental Project ______%
- ☐ Public Project ______%
- ☐ Private Project ______%

1.2 Major types of construction projects undertaken by your company and their normal percentage:

- ☐ National Civil Project ______%
- ☐ Local Civil Project ______%
- ☐ Industrial Project ______%
- ☐ Commercial Project ______%
- ☐ Residential Project ______%
- ☐ Electrical Works ______%
- ☐ Water Supply–Drainage Works ______%

☐ Heating and Ventilating Works ______%
☐ Gas Supply Works ______%
☐ Others ______%

1.3 Total annual contracts of your company in 2000 is ____________ million dollars (RMB), and normal annual contracts is ____________ million dollars (RMB).

1.4 Total expenditure for environmental management (EM) of your company in 2000 is ____________ dollars, and normal annual expenditure is ____________ dollars.

1.5 There are ____________ administrators in your company, and ____________ of them are involved in EM.

1.6 There are ____________ subcontractors working with your company now, and normally there are ____________ subcontractors.

1.7 There are ____________ subcontractors working with your company who have ISO 14001 accreditations.

1.8 There are ____________ material and machine suppliers for your company, and normally there are ____________ suppliers.

1.9 There are ____________ suppliers for your company who have ISO 14001 accreditations.

1.10 State of ISO 14001 certification for your company:

☐ Registered. Requested at year ______, obtained at year ______, and it took about ______ months.
☐ Under assessment. Requested at year ______, will obtain at year ______, and it took about ______ months.
☐ Failed. Requested at year ______, failed at year ______, and it took ______ months.
☐ Registered but expired. Registered at year ______, took ______ months, and expired at year ______.
☐ Have not applied for, but preparing to. Will request at year ______.
☐ Do not want to apply. (Please ignore questions 1.11–1.14.)

1.11 Total expense for ISO 14001 certification of your company is ______ million dollars.

1.12 Total acceptable expense for adoption and implementation of environmental management system based on ISO 14001 in your company: (Unit is Chinese dollars (RMB))

☐ Free
☐ Less than 0.1 million
☐ 0.10–0.25 million
☐ 0.25–0.50 million
☐ 0.5–0.75 million
☐ more than 0.75 million

1.13 Reasons for applying for ISO 14001 registration of your company:

Potential reasons	*Grade of influence (influence increase by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
International competitive pressure										
National competitive pressure										
Management standardization										
Improving document-handling in company										
Reduce project cost										
Obey laws and regulations										
Client's request										
Conscious of environmental protection										
Others (Please specify)										

1.14 Main considerations while applying for ISO 14001 registration for your company:

Considerations	*Grade of influence (influence increase by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Cost of implementation										
Investment of additional human resource										
Burden of EM document										
Combination with other management works										
Restructure organization										
Profits										
Others (Please specify)										

1.15 Potential benefits of ISO 14001 registration for your company:

Potential benefits	*Grade of benefits (benefits increase by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Enlarge occupation in market										
Increase productivity										
Decrease harm to environment										
Increase company's profits										
Improve trading and public status										
Fulfill clients' demands										
Others (Please specify)										

1.16 Extent of desire of applying for ISO 14001 certification of your company:

☐ Strongly reject
☐ Reject, but can be considered
☐ Not decided yet
☐ Accept, but need consideration
☐ Strongly accept

1.17 Will your company apply for an update of ISO 14001 registration in the future?

☐ Definitely not
☐ May not
☐ Unsure
☐ Maybe
☐ Definitely yes

1.18 Why does your company not think of applying for an ISO 14001 certificate?

☐ Higher cost
☐ No interest
☐ Small profits
☐ Not necessary
☐ Lack of professionals

- ☐ Conflicts in organization
- ☐ Lesson from failure on EM
- ☐ Others (Please specify)

Part 2 Adoption and implementation of ISO 14001 EMS and internal EMS
(Please check all that applies)

2.1 Do you have any other internal EMS except ISO 14001 EMS in your company?

- ☐ Have
- ☐ Not have (Please skip to question 2.5)
- ☐ Under construction
- ☐ Failed

2.2 Your internal EMS is

- ☐ Internal total quality and environmental management system
- ☐ Internal EMS
- ☐ Others (Please specify)

2.3 Do you implement EM according to ISO 14001 EMS and internal EMS?

- ☐ Both ISO 14001 EMS and ISO 9000 QMS
- ☐ ISO 14001 EMS only
- ☐ Internal TQEMS only
- ☐ Internal EMS only
- ☐ ISO 14001 EMS and Internal TQEMS
- ☐ ISO 14001 EMS and Internal EMS
- ☐ Others

2.4 The EM in your company focuses on

- ☐ Energy efficiency
- ☐ Control and reduction of quantity of waste
- ☐ Control and reduction of noise
- ☐ Control and reduction of air pollution
- ☐ Recycling materials and equipment
- ☐ Recycling waste materials and packing
- ☐ Control and reduction of accident
- ☐ Control and reduction of geological deformation
- ☐ Others (Please specify)

2.5 Your opinion about the pertinent factors on environmental impact of construction projects

Pertinent factors	*Grade of pertinence (pertinence increase by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Governmental (national and local) laws and statutes										
Governmental civilians' attitude on executing the laws										
ISO 14001 registration										
Subcontractors' attitude towards cooperation										
Interior collectivism										
Exterior competitive pressure										
Requirements from clients										
Company's profit										
Company's consciousness of environmental protection										
Construction technologies										
Construction materials and machines										
Others (Please specify)										

Part 3 Advantages and disadvantages of adoption and implementation of the ISO 14000 series

3.1 Advantages of adoption and implementation of the ISO 14000 series are that it can

Advantage	*Grade of advantage (advantage increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Increase occupancy on the market										
Enhance visualization and celebrity										

Advantage	*Grade of advantage (advantage increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Increase profit										
Improve productivity										
Improve quality										
Decrease duration of a construction project										
Protect environment										
Increase the degree of clients' satisfaction										
Improve the efficiency of EM										
Others (Please specify)										

3.2 Disadvantages of adoption and implementation of the ISO 14000 series are

Disadvantage	*Grade of disadvantage (disadvantage increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Cost of registration										
Preparative work in earlier stage										
Cost of implementation										
Change of processes of project management										
Additional human resource										
Change of internal EMS										
Change of internal organizational structure										
Others (Please specify)										

Part 4 Perceptions of the ISO 14000 series of standards and EMS

4.1 Perceptions of the ISO 14000 series of standards on different administrative levels

Internal administrative level	*Grade of perception (perception increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Worker										
Common employee										
Junior manager										
Project manager										
Senior manager										

4.2 Perceptions of EMS on different administrative levels

Internal administrative level	*Grade of perception (perception increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Worker										
Common employee										
Junior manager										
Project manager										
Senior manager										

Part 5 Some correlated questions about the ISO 14000 series and EM

5.1 Your opinion about the statement, "The ISO 14000 series is necessary and important for your company to adopt and implement EMS"

☐ Strongly agree
☐ Agree
☐ Neutral
☐ Disagree
☐ Strongly disagree

5.2 Your opinion about the statement, "The ISO 14000 series is contributive to your company in improving EM"

- ☐ Strongly agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly disagree

5.3 Your opinion about the statement, "EMS is essential for a construction company to improve EM"

- ☐ Strongly agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly disagree

5.4 Your opinion about the statement, "It is necessary to implement internal EMS and adopt ISO 14000 at the same time"

- ☐ Strongly agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly disagree

5.5 Your opinion about the statement, "The cost of EM is important than EM itself"

- ☐ Strongly agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly disagree

5.6 Your opinion about the statement, "Activity-costing control can be a good tool for managing the cost of EM"

- ☐ Strongly agree
- ☐ Agree
- ☐ Neutral
- ☐ Disagree
- ☐ Strongly disagree

5.7 Your opinion about the statement, "Similar to the use of air pollution index to evaluate air quality in cities, construction pollution index (CPI) of an activity can be used to evaluate environmental impact of a construction activity. The CPI can be an efficient approach for EM through the control of activities' CPI and, by implication, the project's CPI under an acceptable cost"

☐ Strongly agree
☐ Agree
☐ Neutral
☐ Disagree
☐ Strongly disagree

5.8 Your opinion about the statement, "It is important for a contractor to consider about the environmental impact of materials when he wants to select a supplier, similarly, it is important for a contractor to consider about the implementation of EMS in construction when he wants to select a subcontractor"

☐ Strongly agree
☐ Agree
☐ Neutral
☐ Disagree
☐ Strongly disagree

5.9 Your opinion about the statement, "Waste and second-hand materials and equipment can be traded by using an exchange platform/portal on the Internet, and then the total waste from the construction industry can be reduced. So the electronic commerce firm can be a commercial associate with construction companies on their EMS"

☐ Strongly agree
☐ Agree
☐ Neutral
☐ Disagree
☐ Strongly disagree

Part 6 Potential influences on adopting the ISO 14000 series in construction companies

Potential influential reasons	*Grade of influence (influence increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Governmental requirement on adopting the ISO 14000 series in construction industry										
Governmental encouragement on financial subsidies, e.g. tax deduction/return										
Governmental encouragement on non-financial allowance										
Competitive pressure from international construction industry within WTO										
Competitive pressure from domestic construction industry										
Cost of implementation of the ISO 14000 series EMS (About RMB 0.3M)										
Cost of ISO 14001 registration (About RMB 50,000)										
Internal initiative consciousness on implementation of EMS										
Requirement and pressure from clients or suppliers										
Expectation from clients or suppliers										
Introducing the ISO 14000 series for establishing enterprise's internal EMS										
Encouraging subcontractors to adopt ISO 14001 for improving the level of EM										

(Continued)

Potential influential reasons	*Grade of influence (influence increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Various additional EM documents on adopting ISO 14001										
Interruption and adjustment of construction processes on implementing ISO 14001										
Entire employees' training and education before implementing ISO 14001 EMS										
Additional cost on training functionaries inside company										
The necessity of management involvement on adopting ISO 14001										
Cost of ISO 14001 EMS assessment, certification, and maintenance										
Additional cost of human resource on adopting and implementing ISO 14001										
Additional cost of reorganization on adopting and implementing ISO 14001										
Lack of reliable consulting companies on tutorship of adoption of ISO 14001										
Additional cost of failure on adopting ISO 14001 EMS										

Part 7 Potential influences on implementing the ISO 14000 series in construction companies

Potential influential reasons	*Grade of influence (influence increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Additional cost of implementation of ISO 14001 EMS										
Employees' attitude towards cooperation on implementation of ISO 14001										
Administrators' attitude towards cooperation on implementation of ISO 14001										
Subcontractors' attitude towards cooperation on implementation of ISO 14001										
Suppliers' attitude towards cooperation on implementation of ISO 14001										
Impacts and additional expense of interruption and adjustment on construction										
Success or failure in adjustment of organizational structure inside the enterprise										
Success or failure in combination with other EMSs inside the enterprise										
Success or failure in the maintenance and continuous assessment of ISO 14001 EMS										
Success or failure in employees' training and education inside the enterprise										
Success or failure in administrator's training and education inside the enterprise										

(Continued)

Potential influential reasons	*Grade of influence (influence increases by degrees from 1 to 10)*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Lack of pressure from the government										
Lack of pressure from the clients										
Lack of pressure from the competitors inside construction industry										
No competitors implement the ISO 14000 series first inside the construction industry										
High expense on implementation										
Multifarious documental operation process of ISO 14001										
Lack of suitable technology and material for environmental protection										
Applicability of the ISO 14000 series in construction enterprises										
Correspondence and cooperation of design and construction										

Part 8 Additional comments

Thank you for your participation! For further contacts, please provide the following information:

Company Name:	
Website:	
Business Scope:	
Grade:	
Contact Person:	
Position:	
Mail Address:	
City/Province:	Postcode:
Telephone:	E-mail:

Appendix B

A decision-making model

B.1 Introduction

The analysis presented in Chapter 2 identified that there are five classes (critical factors) directly affecting the acceptability of the ISO 14000 series in the Shanghai construction industry. In this appendix, the five critical factors are integrated into a decision-making model which can assess whether a contracting company is positive or negative to the acceptance of the ISO 14000 series. In addition, the model can also enable contractors to identify weak aspects in adopting and implementing the ISO 14000 series, assuming that they are willing to accept the ISO 14000 series.

Discriminant analysis is used to develop the decision-making model as it is useful in situations where one wants to build an evaluation model of group membership based on observed characteristics of each case and an established predictive model can then be applied to new cases with measurements for the predictor variables for unknown group membership (Norusis 2000). Such an analysis method has also been used to develop an evaluation model for a company's decision to adopt ISO 14001 in Singapore (Quazi *et al.* 2001).

There are two basic requirements in using the discriminant analysis in statistical inferences: one is that the independent variables obey a normal distribution, another is that the independent variables are linearly related to the dependent variable (Norusis 2000). The procedure of a discriminant analysis generates a discriminant function based on linear combinations of the normally distributed predictor variables that provide the best discrimination between the contractors who are either positive or negative to acceptance of the ISO 14000 series. Therefore, before using the discriminant analysis, it is necessary to ensure that the five critical factors satisfy the two basic requirements.

Let us assume that the five critical factors are independent variables and are represented by C_{5C} (Classes of 5C), where C_{comd}, C_{cond}, C_{comp}, C_{coop}, and C_{cost} represents the Classes of the governmental Command-and-control regulations, the technology Conditions, the Competitive pressures, the Cooperative attitude, and the Cost–benefit efficiency, respectively. The acceptability of the ISO 14000 series is a dependent variable and is represented by $A_{ISO\ 14k}$ (e.g. for accepters, $A_{ISO\ 14k} = 1$; for others, $A_{ISO\ 14k} = 0$).

B.2 Probability Distributions of the C_{5C}

A normal probability plot, e.g. Q-Q (quantile-quantile) plot, is generally used to check whether variables follow a normal distribution when one wants to assess normality (Norusis 2000). In the quantitative analysis of the survey data, the Q-Q plot is applied to identify and assess normality of each class of the C_{5C}. The finished Q-Q plots, as shown in Figure B.1, indicate that all five classes, with observed significance levels approximately below 0.01 in the Kolmogorov-Smirnov statistical tests of normality, are normally distributed. This is because if the sample is from a normal distribution, points will cluster around a straight line in a Q-Q plot and if the observed significance level is small enough, usually less than 0.05 or 0.01, the null hypothesis is rejected (Norusis 2000).

B.3 Linear relationships between the C_{5C} and the $A_{ISO\ 14k}$

The linear relationships between the C_{5C} and the $A_{ISO\ 14k}$ can be measured by both quantitative indices and graphic matrix in the SPSS®. The quantitative indices used are normally tolerance and variance inflation factor (VIF). The tolerance is a statistical value used to determine how much the independent variables are

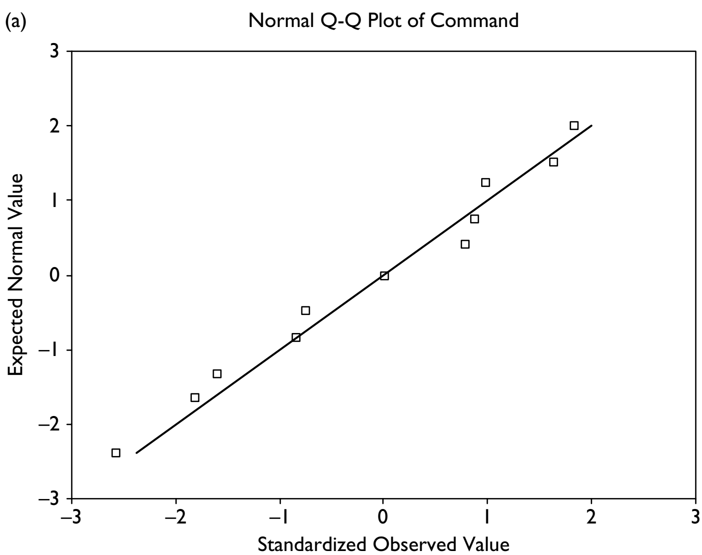
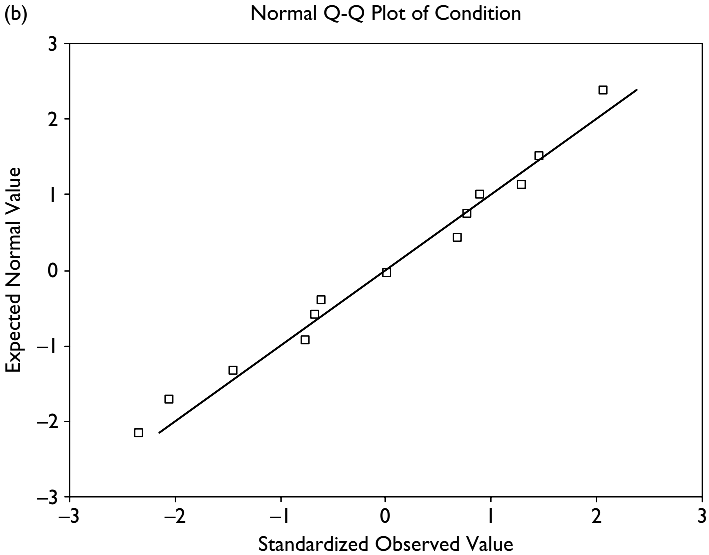


Figure B.1 Normal Q-Q plots of the C_{5C} with total 72 respondents. Normal Q-Q plots of Class 1: governmental regulations; Normal Q-Q plots of Class 2: technology conditions; Normal Q-Q plots of Class 3: competitive pressures; Normal Q-Q plots of Class 4: cooperative attitude; Normal Q-Q plots of Class 5: Cost–benefit efficiency.

(b)



(c)

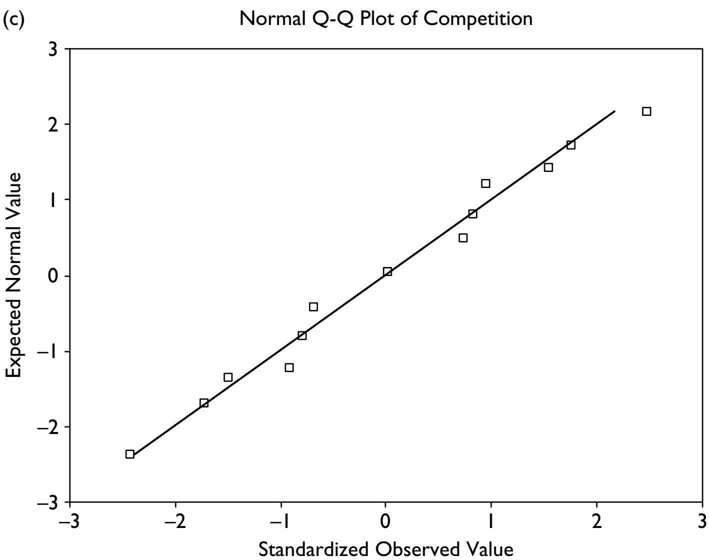
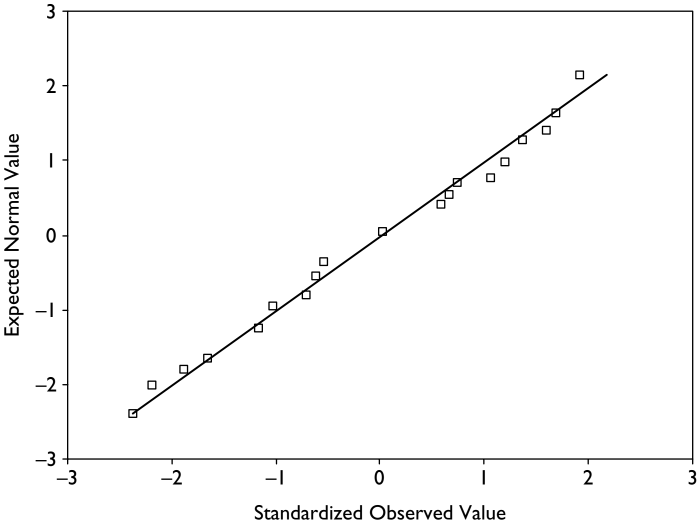
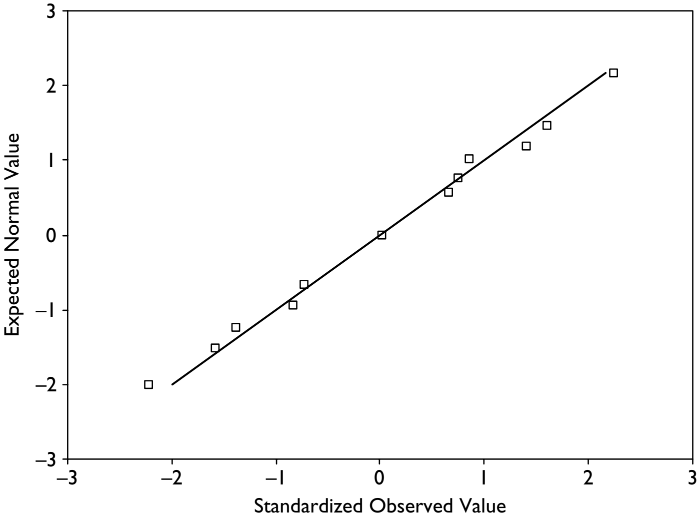


Figure B.1 (Continued).

(d) Normal Q-Q Plot of Cooperation



(e) Normal Q-Q Plot of Cost



Notes

One-Sample Kolmogorov-Smirnov Test (Test distribution is Normal)

class 1: Governmental regulations: Significance = 0.000;

class 2: Technology conditions: Significance = 0.007;

class 3: Competitive pressures: Significance = 0.000;

class 4: Cooperative attitude: Significance = 0.000;

class 5: Cost–benefit efficiency: Significance = 0.000.

Figure B.1 (Continued).

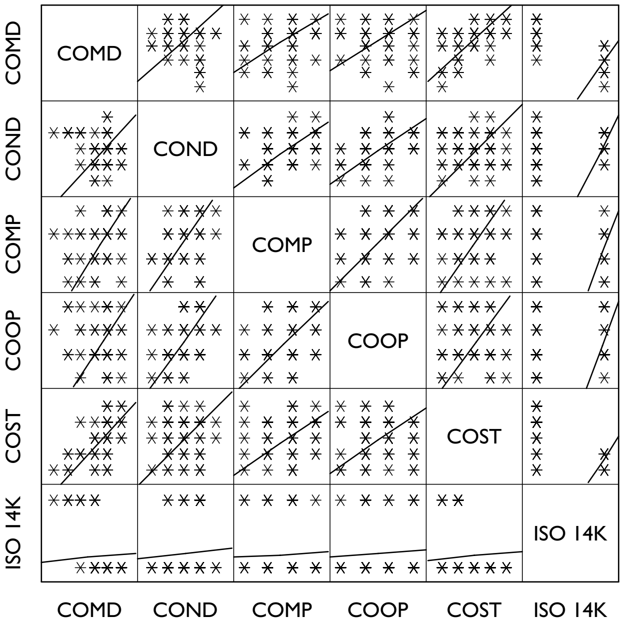


Figure B.2 Collinearity statistics of the C_{5C} and the $A_{ISO\ 14k}$ (Scatterplot matrix).

linearly related to one another (multicollinear) and a variable with very low tolerance contributes little information to a model and thus brings noise to the resultant model; and the VIF is a reciprocal of the tolerance, and a large VIF value is an indicator of multicollinearity (Norusis 2000). The calculated results of these two indices are listed in Figure B.2. Since no value of VIF exceeds 10, it can be concluded that values of both tolerance and VIF indicate inconsequential coollinerity between the C_{5C} (Field 2000; Quazi *et al.* 2001). On the other hand, the graphic matrix, such as a scatterplot matrix, can be used to check for linearity of variances by plotting any two of the dependent variables. The scatterplot matrix of the C_{5C} and the $A_{ISO\ 14k}$ (refer to Figure B.2) suggests that although all of the independent variables have inconsequential linear relationships with the dependent variable $A_{ISO\ 14k}$, fit line can be drawn through some fit methods, such as a linear regression.

B.4 Discriminant function for C_{5C} and $A_{ISO\ 14k}$

Based on the discriminant analysis with C_{5C} and $A_{ISO\ 14k}$ using the SPSS®, a multiple linear regression equation that predicts the ISO 14000 series' acceptability

Table B.1 Discriminant function coefficients for linear acceptability evaluation model

	Canonical discriminant function	*Classification function coefficients (Fisher's linear discriminant functions)*	
	Standardized	$A_{ISO\ 14k} = 0$	$A_{ISO\ 14k} = 1$
α_0	0.000	−108.470	−84.170
α_{comd}	+1.026	9.383	5.850
α_{cond}	−0.112	4.882	5.203
α_{comp}	−0.274	5.368	6.224
α_{coop}	−0.043	1.194	1.298
α_{cost}	+0.302	5.430	4.574

Table B.2 Classification results of the linear acceptability evaluation model

Original actual group	*Sample size*	*Predicted group of non-accepters*	*Predicted group of accepters*
Group of non-accepters	58	54	4
Group of accepters	14	4	10

Note
88.9% of originally grouped cases are correctly classified using Equation B.1.

is developed in Equation B.1, and all coefficients in Equation B.1 are presented in Table B.1.

$$A_{ISO\ 14k} = \alpha_0 + \alpha_{comd}\,\overline{C}_{comd} + \alpha_{cond}\,\overline{C}_{cond} + \alpha_{comp}\,\overline{C}_{comp} + \alpha_{coop}\,\overline{C}_{coop} + \alpha_{cost}\,\overline{C}_{cost} \tag{B.1}$$

where α_i represents coefficients, and $\overline{C}_i$ represents the average score of each class.

Using Equation B.1 to run through the whole sample population, the linear discriminant model (Equation B.1) correctly classified 88.9% of the companies into the two groups (refer to Table B.2). This percentage is within the range specified by Quazi *et al.* (2001), which indicates that the discriminant model is useful.

B.5 Validation

The linear discriminant function (Equation B.1) has also been validated by using data from our follow-up questionnaire (see Appendix A) surveys conducted among main contractors in five representative cities in mainland China, where the average EIA rate was 85% and the average ISO 14001 registration rate was 0.06%. The validation results indicate that the total rate of correct classification with Equation B.1 is as low as 78% (refer to Table B.3), and the highest correct match rate occurs with samples from Shanghai, where Equation B.1 is used.

As a result, because the inconsequential co-linearity between both of the independent variables and the dependent variable surpasses the boundary of the assumption of a discriminant analysis in linear regression, the pure linear predictive model is almost rejected not only in this research but also in another (Quari *et al.* 2001) with a similar correct classification rate. Moreover, our further attempts in making a multiple nonlinear acceptability evaluation model can provide a correct classification rate higher than 88.9% for the time being, and it indicated that a multiple nonlinear regression equation is necessary.

B.6 Model application

The linear discriminant model can be applied to assist contractors to make decisions on whether to adopt and implement the ISO 14000 series. The model can also be used to identify weak aspects of a contracting company in adopting and implementing the ISO 14000 series, assuming the company accepts the ISO 14000. The reasoning mechanism of the model can be expressed as follows:

FOR $i = 1$ to 5
IF $S_1 > \overline{C}_1$ or $S_2 < \overline{C}_2$ or $S_3 < \overline{C}_3$ or $S_4 < \overline{C}_4$ or $S_5 > \overline{C}_5$
THEN display Sug_i
OTHERWISE display *Congratulations! Your company is ready to have ISO 14001 accreditation.*

Table B.3 Revaluation results of the linear acceptability evaluation model

City name	*Sample size*	*Correct match*	*Wrong match*	*Rate of correct classification (%)*
Shanghai	20	18	2	90
Tsingtao	20	16	4	80
Jinan	20	15	5	75
Chengdu	20	14	6	70
Chongqing	20	15	5	75
Total	100	78	22	78

Table B.4 Checklist for decision-making on acceptance of the ISO 14000 series

Class and its item	*Importance score (1–10)*	*Suggestion*
1 Governmental regulations 1.1 Governmental administrative requirement on adopting the ISO 14000 series 1.2 Governmental encouragement on financial subsidies, e.g. tax deduction/return 1.3 Governmental encouragement on non-financial allowance 1.4 Pressure from the government	$\overline{C}_1$	Sug_1
2 Technology conditions 2.1 Reliable consultant companies on tutorship of adoption of the ISO 14000 series 2.2 Multifarious documental operation process of the ISO 14000 series 2.3 Destitute of applicability of the ISO 14000 series in construction enterprises 2.4 Suitable technology and material for environmental protection	$\overline{C}_2$	Sug_2
3 Competitive pressures 3.1 Competitive pressure from domestic construction industry 3.2 Competitive pressure from international construction industry 3.3 Pressure from the competitors inside construction industry 3.4 No competitors implemented the ISO 14000 series first inside construction industry 3.5 Pressure from the clients	$\overline{C}_3$	Sug_3
4 Cooperative attitude 4.1 Internal initiative consciousness on implementation of EMS 4.2 Correspondence and cooperation of design and construction 4.3 Employees' attitude towards cooperation on implementing the ISO 14000 series 4.4 Administrators' attitude towards cooperation on implementing the ISO 14000 series 4.5 Subcontractors' attitude towards cooperation on implementing the ISO 14000 series 4.6 Suppliers' attitude towards cooperation on implementing the ISO 14000 series	$\overline{C}_4$	Sug_4

Table B.4 (Continued)

Class and its item	*Importance score (1–10)*	*Suggestion*
5 Cost–benefit efficiency	$\overline{C}_5$	Sug_5
5.1 Cost of implementation of ISO 14001 EMS		
5.2 Cost of ISO 14001 EMS assessment, certification, and maintenance		
5.3 Additional cost of human resource on adopting and implementing the ISO 14000 series		
5.4 Cost of ISO 14001 registration		
5.5 Additional cost of implementation of ISO 14001 EMS		
5.6 Impacts and additional expense of construction on interruption and adjustment		
5.7 High expense on implementation		
$A_{ISO\ 14k}$		

where S_i represents the average importance score of class i ($i = 1$ to 5), $\overline{C}_i$ represents the average value of class i, which is calculated from values given by accepters in the questionnaire survey, and the Sug_i represents suggestions to be provided to the class i about how one can improve performance on each item so as to achieve the requirements of the ISO 14000 series. The suggestions are developed from five useful findings from the analysis of the survey results:

- Contractors who give higher score to Class 1 have less intention to accept ISO 14000;
- Contractors who give higher score to Class 2 have more intention to accept ISO 14000;
- Contractors who give higher score to Class 3 have more intention to accept ISO 14000;
- Contractors who give higher score to Class 4 have more intention to accept ISO 14000;
- Contractors who give higher score to Class 5 have less intention to accept ISO 14000.

The model is implemented in a 45×3 spreadsheet of Microsoft Excel®, where the five classes and their associated items are listed in a checklist, as shown in Table B.4. Every item of the classes needs to be graded by users using the importance score ranging from 1 to 10, where 1 represents minimal importance and 10 represents maximal importance. When all items of the classes are valued, the spreadsheet generates average grade scores of each class and $A_{ISO\ 14k}$ is then calculated. If the value of $A_{ISO\ 14k}$ is 0, then suggestions (Sug_i) are provided to users on how to improve performance.

Appendix C

Sample waste exchange websites

Abbreviation	*Website details*
BCC	BuildFind Construction Classfieds <http://classifieds.buildfind.com/> (accessed in 2000–2003)
BRS	BuildingResources <http://www.buildingresources.org/>
BWE	Beyond Waste <http://www.sonic.net/~precycle/>
CDE	C&D Material Exchange <http://www.info.gov.hk/epd/misc/cdm/en_exchange1.html>
CMX	California Materials Exchange <http://www.ciwmb.ca.gov/CalMAX/>
CWE	The Commercial Waste Exchange <http://www.wastechange.com/>
HHM	Happy Harry's Used Building Materials <http://www.happyharry.com/hhub.htm>
HME	Hawaii Materials Exchange <http://www.maui.net/~mrghimex/himex1.html>
IDS	Industry Deals <http://www.industrydeals.com> (accessed in 2000–2003)
IME	Indiana Materials Exchange <http://www.state.in.us/idem/imex/>
IMX	Industrial Materials Exchange <http://www.metrokc.gov/hazwaste/imex/>
IWE	Illawarra Waste Exchange <http://www.globalpresence.com.au/waste_exchange/>
IWN	Industrial Waste Exchange Network <http://www.environ.wa.gov.au/iwe/>
IWX	Integrated Waste Exchange <http://www.capetown.gov.za/apps/iwe/default.asp> (accessed in 2000–2003)
KME	Kentucky Industrial Materials Exchange <http://www.kppc.org/kime/index.html> (accessed in 2000–2003)
LLR	Clubrecycle/Letsrecycle <http://www.letsrecycle.com/index.jsp>
MEX	Materials Exchange <http://www.cheltweb.com/wow/wexhome.htm>
MIE	Materials Information Exchange <http://cig.bre.co.uk/connet/mie/>

(Continued)

Abbreviation	*Website details*
MME	Minnesota Materials Exchange <http://www.mnexchange.org/>
MNY	Western New York Materials Exchange <http://recycle.net/recycle/exch/mat-ex/index.html>
NEE	New England Materials Exchange <http://www.wastecapnh.org/nemex/> (accessed in 2002–2003)
NHE	New Hampshire Materials Exchange <http://www.wastecapnh.org/nhme.htm> (accessed in 2002–2003)
NSE	Nova Scotia Material Exchange <http://www.clean.ns.ca/materials_exchange/wxh.htm> (accessed in 2000–2003)
NYE	New York Wa$te Match <http://www.wastematch.org/>
REN	Resource Exchange Network for Eliminating Waste <http://www.tnrcc.state.tx.us/exec/oppr/renew/renew.html>
RME	Reusable Building Materials Exchange <http://www.rbme.com/>
RSW	Recycler's World <http://www.recycle.net/build/index.html> (accessed in 2000–2003)
SCE	Sonoma County's Materials exchange <http://www.recyclenow.org/sonomax/>
SEE	Southern New England Materials Exchange <http://www.rirrc.org/materials.shtml> (accessed in 2000–2003)
SME	Southeast Minnesota Recyclers' Exchange <http://www.semrex.org/>
SWC	Solid Waste.com <http://www.solidwaste.com/content/homepage/default.asp>
TME	Tennessee Materials Exchange <http://www.cis.utk.edu/tme_titl.htm> (accessed in 2000–2003)
VCE	Ventura county Materials Exchange <http://www.rain.org/~swmd/vcmax/> (accessed in 2000–2003)
WME	Waste Management Commodities Exchange <http://commodities.wm.com/wmx/exchange.nsf>
WRA	The Waste & Resources Action Programme <http://www.wrap.org.uk/>
WUK	Waste Exchange UK <http://www.wasteexchangeuk.com/Template.htm> (accessed in 2000–2003)

Appendix D

Webfill function menu

The Webfill e-commerce system provides its members the following function menu for selection:

Account management

- Member's profile update
- Member's exchange record check
- Request buying/selling/bidding

- ☐ Buyers (Contractor/Managers/Manufacturers/Recycler/Disposers)
  - ☐ Current information for buyers
  - ☐ Search
    - ☐ By type/category of *WasteSpec* (Kincaid, Walker and Flynn 1995)
    - ☐ By brand of recovered materials
    - ☐ By status (fixed price, bidding price, rent)
    - ☐ By date
  - ☐ Bid
    - ☐ By type/category
    - ☐ By bidding code of current bidding item on buyers' bulletin board
  - ☐ Request
    - ☐ By type/category
    - ☐ By code of current item on buyers' bulletin board
- ☐ Sellers (Contractor/Managers/Manufacturers/Recyclers/Disposers)
  - ☐ Current information for sellers
  - ☐ Search
    - ☐ By type/category
    - ☐ By brand of recovered materials

    - ☐ By status (fixed price, bidding price, rent)
    - ☐ By date
  - ☐ Bid
    - ☐ By type/category
    - ☐ By bidding code of current bidding item on sellers' bulletin board
  - ☐ Request
    - ☐ By type/category
    - ☐ By code of current item on sellers' bulletin board
- ☐ Transporters
  - ☐ Current information for transporters
  - ☐ Search
    - ☐ By type/category
    - ☐ By master of goods (C&D waste or recovered materials)
    - ☐ By location
    - ☐ By date
  - ☐ Bid
    - ☐ By type/category
    - ☐ By bidding code of current bidding item on sellers' bulletin board
  - ☐ Request
    - ☐ By type/category
    - ☐ By code of current item on sellers' bulletin board

Glossary

Construction Pollution Index (CPI): It is a method to quantitatively measure the amount of environmental pollution and hazards generated from individual processes and the whole project during construction; it can be utilized by indicating the potential level of accumulated environmental pollution and hazards generated from a construction site, and by reducing or mitigating pollution level during construction planning stage.

Environmental Impacts Assessment (EIA): It is a process to identify, predict, evaluate, and mitigate the biophysical, social, and other relevant environmental effects of development proposals or projects prior to major decisions being taken and commitments made.

Env.Plan: It is a multicriteria decision-making model for evaluating construction plan alternatives based on analytic network process (ANP) theory and experts' knowledge. The CPI and the env.Plan are two essential tools for preventing potential adverse environmental impacts at pre-construction stage.

E+: It is an integrative methodology for effective, efficient, and economical EM in construction projects, in which an EMS-based dynamic EIA process is applied inside a knowledge-driven decision-support system for active knowledge capture and re-use focusing on environmental-conscious construction management.

Incentive Reward Program (IRP): It is a financial incentive program (FIR), which can be utilized as an on-site material and equipment management system to control and reduce construction waste. Information systems using bar-code technology or radio frequency identification (RFID) technology can facilitate its implementation.

Webfill: It is an online waste exchange approach or an e-commerce business plan, which is developed based on e-commerce theory and the trip-ticket system being used for waste disposal management in Hong Kong. It can be utilized to reduce the final amount of construction and demolition (C&D) waste to be land-filled.

References

Abdelhamid, T.S., and Everett, J.G. (1999). Physiological demands of concrete slab placing and finishing work. *Journal of Construction Engineering and Management*, ASCE, 125(1), 47–52.

Abdullah, A., and Anumba, C.J. (2002a). Decision criteria for the selection of demolition techniques. *Proceeding of the Second International Postgraduate Research Conference in the Built and Human Environment*. University of Salford, 11–12 April 2002, edited by M. Sun, *et al.* Blackwell Publishers. 410–419.

Abdullah, A., and Anumba, C.J. (2002b). Decision model for the selection of demolition techniques. *Proceeding of the International Conference on Advances in Building Technology*. The Hong Kong Polytechnic University, 4–6 December 2002. Elsevier Science Limited. 1671–1681.

Abudayyeh, O., Sawhney, A., El-Bibany, H., and Buchanan, D. (1998). Concrete bridge: Demolition methods and equipment. *Journal of Bridge Engineering*, 3(3), 117–125.

Adams, T.M., Malaikrisanachalee, S., Blazquez, C., and Vonderohe, A. (2000). GIS-based automated oversize/overweight permit processing. In R. Fruchter (editor), F. Peña-Mora, W.M.K. Roddis (Ed.), *Computing in Civil and Building Engineering* (Proceedings of the Eighth International Conference held in Stanford, California, 14–16 August 2000), ASCE, Reston, 209–216.

Adams, T.M., Vonderohe, A.P., Russell, J.S., and Clapp, J.L. (1992). Integrating facility delivery through spatial information. *Journal of Urban Planning and Development*, ASCE, 118(1), 13–23.

Adeli, H., and Karim, A. (2001). *Construction Scheduling, Cost Optimization and Management: A New Model Based on Neurocomputing and Object Technologies*. Spon Press, London and New York.

Ammenberg, J., Borjesson, B., and Hjelm, O. (2000). Joint EMS and group certification: A cost-effective route for SMEs to achieve ISO 14001. In *ISO 14001: Case Studies and Practical Experiences*, edited by H. Ruth. Greenleaf Publishing Ltd, Sheffield, UK. 58–66.

Anumba, C.J., Abdullah, A., and Fesseha, T. (2003). Selection of demolition techniques: A case study of the Warren Farm bridge. *Structural Survey*. Emerald, MCB UP Limited, 21(1), 36–48.

Arnfalk, P. (1999). *Information Technology in Pollution Prevention: Teleconferencing and Telework used as Tools in the Reduction of Work Related Travel*, IIIEE Dissertations, the International Institute for Industrial Environmental Economics at Lund University, Sweden.

Austin, T. (1991). Building green. *Civil Engineering*, ASCE, 61(8), 52–54.

Azani, C.H. (1999). An integrative methodology for the strategic management of advanced integrated manufacturing systems, in *Advanced Manufacturing Systems: Strategic Management and Implementation*, edited by J. Sarkis and H.R. Parsaei. Gordon and Breach Science Publishers, Australia, 21–41.

Bakken, J.D., and Avey, C.M. (1992). Integration of AM/FM/GIS with MODELING/DESIGN on large utility PC network. In B.J. Goodno, J.R. Wright (Editors), *Computing in Civil Engineering and Geographic Information Systems Symposium* (Proceedings of the Eighth Technical Council on Computer Practices Conference held in conjunction with A/E/C Systems '92), ASCE, New York, 703–711.

Baldwin, A.N., Thorpe, A., and Alkaabi, J.A. (1994). Improved materials management through bar-coding: Results and implications from a feasibility study. *Proceedings of Institute of Civil Engineers: Civil Engineering*, 102(6), 156–162.

Bell, L.C., and McCullouch, B.G. (1988). Bar code application in construction. *Journal of Construction Engineering and Management*, ASCE, 114(2), 263–278.

Bello, D., Virji, M.A., Kalil, A.J., and Woskie, S.R. (2002). Quantification of respirable, thoracic, and inhalable quartz exposures by FT-IR in Personal Impactor Samples from Construction Sites. *Applied Occupational and Environmental Hygiene*, Taylor and Francis Ltd, 17(8), 580–590.

Berning, P.W., and Diveley-Coyne, S. (2000). E-Commerce and the construction industry: The revolution is here. *Industry Reports Newsletters*. Thelen Reid and Priest LLP, New York. <http://www.constructionweblinks.com/Resources/Industry_Reports__ Newsletters/Oct_2_2000/e-commerce.htm> (20 August 2002).

Bernold, L.E. (1990a). Testing barcode technology in construction environment. *Journal of Construction Engineering and Management*, ASCE, 116(4), 643–655.

Bernold, L.E. (1990b). Barcode-driven equipment and materials tracking for construction. *Journal of Computing in Civil Engineering*, ASCE, 4(4), 381–395.

Bernold, L.E. (2002). Spatial Integration in construction. *Journal of Construction Engineering and Management*, ASCE, 128(5), 400–408.

Bernstein, C.S. (1983). Highway Projects – Can they be done in half the time? *Civil Engineering*, ASCE, 53(9), 50–54.

Blakey, L.H. (1990). Barcode: prescription for precision, performance, and productivity. *Journal of Construction Engineering and Management*, ASCE, 116(3), 468–479.

Boggess, G., and Abdul, M. (1997). *The Application of Genetic Algorithms to the Scheduling of Engineering Units*. A Report to the U. S. Army Corps of engineers Waterways Experiment Station Geotechnical Laboratory Mobility Systems Division. Computer Science Department, Mississippi State University. USA.

Bonforte, G.A., and Keeber, G. (1993). Tunnel repairs under traffic and community impacts. *Infrastructure Planning and Management* (consists of papers presented at two parallel conferences held in Denver, Colorado, 21–23 June 1993). ASCE, New York, 187–191.

Bossink, B.A.G., and Brouwers, H.J.H. (1996). Construction waste: Quantification and source evaluation. *Journal of Construction Engineering and Management*, ASCE, 122(1), 55–60.

Bossler, J.D. (2001). *Manual of Geospatial Science and Technology*, Taylor & Francis London and New York.

Brandon, T.L., and Stadler, R.A. (1991). Use of barcode technology to simplify sieve analysis data acquisition. *Geotechnical Engineering Congress 1991* (Volume 1): Proceedings of the Congress sponsored by the Geotechnical Engineering Division of the American Society of Civil Engineers. (Edited by F.G. McLean, D.A. Campbell and D.W. Harris) (Geotechnical Special Publication No. 27), ASCE, 556–561.

BSI (2000). *BS 6187:2000 – Code of Practice for Demolition*. British Standards Institution (BSI), British Standards Publishing Limited (BSPL). UK.

CACEB (2002). *The Directory of ISO 14001 Certified Companies* (*as at 31 December 2001*). China Registration Committee for Environmental Management System Certification Bodies (CACEB), China. <http://www.naceca.org/> (26 December 2002).

Carberry, E. (1996). Assessing ESOPs. *Journal of Management in Engineering*, ASCE, 12(5), 17–19.

Carper, K.A. (1990). Environmental permitting a major expressway facility in Florida. *Optimizing the Resources for Water Management: Proceedings of the 17th Annual National Conference*, Water Resources Planning and Management Division, ASCE, Fort Worth, Texas, USA, 144–148.

CCEMS (China Center for EMS) (2001). *The Directory of ISO 14001 Certified Companies* (*as at 23 November, 2001*). <http://www.ccems.com.cn/news/news-index.html> (23 November 2001).

CEC (2001). *The Directory of ISO 14001 Certified Companies by CEC* (*as at 22 November, 2001*). Certification Center of Environmental Management System (CEC), Chinese Research Academy of Environmental Sciences, China. <http://www.chinaiso14000-series.com/roster1.htm> (22 November 2001).

CED (2002). *Management of Public Filling Facilities and Dumping Licences*. Civil Engineering Department (CED), Hong Kong ASR Government, Hong Kong. <http://www.info.gov.hk/ced/eng/services/licences/licence.htm> (2 August 2002).

CEIN (2001a). *Main Indicators on Construction Enterprises*. <http://www.cein.gov.cn/home/hytj/jzyhytj/1998/14-1.doc> (22 November 2001).

CEIN (2002). *Main Indicators on Construction Enterprises*. China Engineering Information Net (CEIN), China. <http:// www.cein.gov.cn/> (26 December 2002).

Chan, W.T., Chua, D.K.H., and Kannan, G. (1996). Construction resource scheduling with genetic algorithms. *Journal of Construction Engineering and Management*, ASCE, 122(2), 125–132.

Chang, T.C., William, C., and Crandall, K.C. (1990). Network resource allocation with support of a fuzzy expert system. *Journal of Construction Engineering and Management*, ASCE, 116(2), 239–259.

Chen, Z. (2003). *An Integrated Analytical Approach to Environmental Management in Construction*. Ph.D. Dissertation. Department of Building and Real Estate, Hong Kong Polytechnic University. Hong Kong. ProQuest, USA. UMI Number: AAT 3107430. <http://wwwlib.umi.com/dissertations/ preview/3107430>

Chen, Z., and Li, H. (2003). An analytic network process model for demolition planning. *Proceedings of the CIB Student Chapters International Symposium on Innovation in Construction and Real Estate*. September 2003, Hong Kong Polytechnic University, Hong Kong.

Chen, Z., and Li, H. (2005). A knowledge-driven management approach to environmental-conscious construction. *International Journal of Construction Innovation*, Hodder Arnold, 5(1), 27–39.

Chen, Z., Li, H., and Wong, C.T.C. (2000). Environmental management of urban construction projects in China. *Journal of Construction Engineering and Management*, ASCE, 126(4), 320–324.

Chen, Z., Li, H., and Wong, C.T.C. (2002a). An application of bar-code system for reducing construction wastes. *Automation in Construction*, 11(5), 521–533.

Chen, Z., Li, H., Wong, C.T.C., and Love, P.E.D. (2002c). Integrating construction pollution control with construction schedule: An experimental approach. *Environmental Management and Health*, 13(2), 142–151.

Chen, Z., Li, H., and Wong, C.T.C. (2003a). Webfill before landfill: An e-commerce model for waste exchange in Hong Kong. *Journal of Construction Innovation*, 3(1), 27–43.

Chen, Z., Li, H., and Wong, C.T.C. (2003b). Environmental priority evaluation for construction planning. *Proceedings of the 2nd International Conference on Innovation in Architecture, Engineering and Construction* (*AEC*). June 2003. Loughborough University, UK.

Chen, Z., Li, H., and Wong, C.T.C. (2003c). E+: An integrative methodology for dynamic EIA in construction. *Proceedings of the 3rd International Post-Graduate Research Conference*. April 2003. Salford University, Lisbon, Portugal.

Chen, Z., Li, H., and Wong, C.T.C. (2003d). An integrative methodology for dynamic EM in construction. *Proceedings of the ARCOM Doctoral Workshop*. 18 June 2003. Glasgow Caledonian University, Glasgow, UK.

Chen, Z., Li, H., and Hong, J. (2004a). An integrative methodology for environmental management in construction. *Automation in Construction*, 13(5), 621–628.

Chen, Z., Li, H., Shen, Q.P., and Xu, W. (2004b). An empirical model for decision-making on ISO 14000. *Construction Management and Economics*, 22(1), 55–73.

Chen, Z., Li, H., and Wong, C.T.C. (2005). EnvironalPlanning: An analytic network process model for environmentally conscious construction planning. *Journal of Construction Engineering and Management*, ASCE, 131(1), 92–101.

Cheng, M.Y., and O'Connor, J.T. (1996). ArcSite: Enhanced GIS for construction site layout. *Journal of Construction Engineering and Management*, ASCE, 122(4), 329–336.

Cheng, M.Y., and Yang, S.C. (2001). GIS-based cost estimates integrating with material layout planning. *Journal of Construction Engineering and Management*, ASCE, 127(4), 291–299.

Cheung, C.M., Wong, K.W., Poon, C.S., Fan, C.N., and Cheung, A.C. (1993). *Reduction of Construction Waste: Final Report*. Department of BRE and CSE of the Hong Kong Polytechnic University and the Hong Kong Construction Association Ltd, Hong Kong.

China Environment Daily (16 December 2002). Bureau confirms environmental supervision in pilot national construction projects. *China Environment Daily*, China, p. A4. <http://search.envir.com.cn/info/2002/12/1216921.htm> (26 December 2002).

China EPB (2000). *Official Report on the State of the Environment in China 1999*. Environmental Protection Bureau (EPB), China. <http://www.zhb.gov.cn/bulletin/soechina99/index.htm> (22 November 2001).

China EPB (2002). *Official Report on the State of the Environment in China*. Environmental Protection Bureau (EPB), China. <http://www.zhb.gov.cn/bulletin/country_intro.php3> (26 December 2002).

China NBS (1998). *Statistical Yearbook of China 1997*. National Bureau of Statistics (NBS), China. <http://www.stats.gov.cn/sjjw/ndsj/information/nj97/ml97.htm> (22 November 2001).

China NBS (2000). *Statistical Yearbook of China 1999*. National Bureau of Statistics (NBS), China. <http://www.stats.gov.cn/yearbook/indexC.htm> (22 November 2001).

China NBS (2001). *Statistical Yearbook of China 2000*. National Bureau of Statistics (NBS), China. <http://www.stats.gov.cn/ sjjw/ndsj/zgnj/mulu.html> (22 November 2001).

Chua, D.K.H., Chan, W.T., and Kannan, G. (1996). Scheduling with Co-Evolving Resource Availability Profiles. *Civil Engineering System*, 13(6), 311–329.

CIOB (1997). *Code of Estimating Practice* (6th edition). The Chartered Institute of Building (CIOB), Longman, England.

CIRIA (1993). *Environmental Issues in Construction – A Review of Issues and Initiatives Relevant to the Building, Construction and Relevant Industries. Volume 2 – Technical Review*. Publication SP94, Construction Industry Research and Information Association (CIRIA), Thomas Telford, London.

CIRIA (1994a). *Environmental Assessment*. Publication SP96, Construction Industry Research and Information Association (CIRIA), Thomas Telford, London.

CIRIA (1994b). *Environmental Handbook for Building and Civil Engineering Projects: Checklists, Obligations, Good Practice and Sources of Information.* Publication SP97 and 98, Construction Industry Research and Information Association (CIRIA), Thomas Telford, London.

CIRIA (1995). *A Clients Guide to Greener Construction: A Guide to Help Clients Address the Environmental Issues to be Faced on Building and Civil Engineering Projects*. Publication 120, Construction Industry Research and Information Association (CIRIA), London.

CIRIA (1999). *Environmental Issues in Construction – Research Campaign. Executive Summary*. Publication PR74, Construction Industry Research and Information Association (CIRIA), London.

Clough, R.H., and Antonio, N. (1996). *Environmental Management in Construction: Model Forms to Assist Implementation*. The Chartered Institute of Building (CIOB), UK.

CMC (2000). *Main Applied Construction Technologies in the 10th Five-year Plan*. Official Document No. (2000)286, Technology Department, China Ministry of Construction (CMC), China. <http://www.cein.gov.cn/ show.asp?rec_no=225> (22 November 2001).

CMX (2000). California Materials Exchange (CalMAX). <http://www.ciwmb.ca.gov/CalMAX/> (20 August 2002) (Reached first in 2000).

Coventry, S., and Woolveridge, C. (1999). *Environmental Good Practice on Site*. Construction Industry Research and Information Association (CIRIA), London.

Coventry, S., Woolveridge, C., and Patel, V. (1999). *Waste Minimisation and Recycling in Construction – Boardroom Handbook*. Special Publication 135, Construction Industry Research and Information Association (CIRIA), London.

CPSC (1998). *Environmental Management Systems – Guidelines*. Construction Policy Steering Committee (CPSC), NSW Government, Australia. <http://www.cpsc.nsw.gov.au/environment/> (22 November 2001).

CPSC (2001). Construction Industry CEO Survey: NSW Construction Industry Survey of Industry Leaders. Construction Policy Steering Committee (CPSC), NSW Government, Australia. <http://www.cpsc.nsw.gov.au/docs/ strategic-info/CEO-Survey-Fax-2001.pdf> (22 November 2001).

Darnall, N. (2001). Why some firms mandate ISO 14001 certification while others encourage it. Paper for presentation at the Twenty-Third Annual Research Conference for the Association for Public Policy Analysis and Management Fall Conference: "Public Policy Analysis and Public Policy: Making the Connection", 1–3 November Washington Monarch Hotel, Washington, DC.

Davis, E.W., and Patterson, J.H. (1975). A comparison of heuristic and optimum solutions in resource-constrained project scheduling. *Management Science*, The Institute of Management Sciences, 21(8), 944–955.

Davis, R., Shrobe, H., and Szolovits, P. (1993). What is a Knowledge Representation? *AI Magazine*, 14(1), 17–33.

DeMocker, J. (1999). Building in efficiency. *InternetWeek*. CMP Media LLC. <http://www.internetweek.com/transform/transform112299-1.htm> (26 June 2005).

Dey, P.K., Tabucanon, M.T., and Ogunlana, S.O. (1996). Petroleum pipeline construction planning: A conceptual framework. *International Journal of Project Management*, Elsevier Science Ltd and IPMA, 14(4), 231–240.

Dodds, P.J., and Sternberger, R.S. (1992). The evolution of an environmental monitor. *Civil Engineering*, ASCE, 62(6), 56–58.

Dohrenwend, R.E. (1973). Environmental management during power transmission line construction: Operational considerations. *Annual Meeting Proceedings of the Colloq Biotic Manage Along Power Transmit Rights of Way*, American Institute of Biology Science, Amherst, Mass, USA. NY Bot Gard, Cary Arbor, Millbrook, 58–77.

Echeverry, D. (1996). Adaptation of barcode technology for construction project control. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering* (3rd), edited by J. Vanegas and P. Chinowsky, ASCE, Reston, USA, 1034–1040.

Echeverry, D., and Beltran, A. (1997). Barcode control of construction field personnel and construction materials. *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering* (4th), edited by T.M. Adams, ASCE, Reston, USA, 341–347.

Echeverry, D., Guerra, C.A., and Beltran, A. (1998). A regional attempt to implement barcode control in construction project. In *Computing in Civil Engineering: Proceedings of International Computing Congress in Civil Engineering* (5th), edited by K.C.P. Wang, T. Adams, M.L. Maher and A. Songer, ASCE, Reston, USA, 450–453.

Emery, J.J. (1974). Use of mining and metallurgical waste in construction. *Proceedings of International Symposium on Miner and the Environment*, ASME, Institute of Mine and Metall, London, 261–272.

Enkawa, T., and Schvaneveldt, S. (2001). Just-in-Time, Lean Production, and Complementary Paradigms. In *Handbook of Industrial Engineering: Technology and Operations Management* (3rd edition) edited by G. Salrendy, John Wiley & Sons, Inc., New York. ISBN: 0-471-33057-4.

U.S.EPA (2000). *EPA Region 9 Solid Waste Program: Construction and Demolition (C&D) Debris*. Environmental Protection Agency (EPA), USA. Available at http://www.epa.gov/region09/waste/solid/debris.htm

U.S.EPA (2004a). *FIELDS methods*. Environmental Protection Agency (EPA), USA. <http://www.epa.gov/region5fields/ htm/methods.htm> (9 August 2004).

U.S.EPA (2004b). *GPS – Global Positioning System*. Environmental Protection Agency (EPA), USA. <http://www.epa.gov/region5fields/htm/methods/gps/> (9 August 2004).

U.S.EPA (2004c). *What is GIS (Geography Information Systems)?* Environmental Protection Agency (EPA), USA. <http://www.epa.gov/region5fields/htm/methods/gis/> (9 August 2004).

HKEPD (1997a). *Environment Hong Kong 1997*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (1998a). *Environment Hong Kong 1998*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (1998b). *Monitoring of Solid Waste in Hong Kong 1997*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (1998d). *Solid Waste Statistics 1998 Updates*. Environmental Protection Department (EPD), Hong Kong. <http://www.info.gov.hk/epd/E/pub/sw-rep/98update/Index.htm> (11 August 2004).

HKEPD (1999a). *Environment Hong Kong 1999*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (1999b). *Monitoring of Solid Waste in Hong Kong 1998*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (1999c). *Environmental Protection in Hong Kong*. Environmental Protection Department (EPD), Hong Kong.

HKEPD (1999d). *Trip-ticket System for Disposal of Construction and Demolition Material*. Works Bureau Technical Circular No. 5/99. Environmental Protection Department (EPD), Hong Kong.

HKEPD (2000a). *Environment Hong Kong 2000*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2000b). *Monitoring of Solid Waste in Hong Kong 1999*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (2000c). *Environmental Impact Assessment Ordinance*. Chapter 499, Section 10. Environmental Protection Department (EPD), Hong Kong.

HKEPD (2001a). *Environment Hong Kong 2001*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2001b). *Monitoring of Solid Waste in Hong Kong 2000*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (2002a). *Environment Hong Kong 2002*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2002b). *Monitoring of Solid Waste in Hong Kong 2001*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (2002c). *C&D Material Exchange*. Environmental Protection Department (EPD), Hong Kong. <http://www.info.gov.hk/epd/misc/cdm/ en_exchange.html> (20 August 2002).

HKEPD (2003a). *Environment Hong Kong 2003*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2003b). *Monitoring of Solid Waste in Hong Kong 2002*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/ waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (2004a). *Environment Hong Kong 2004*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/resources_pub/ publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2004b). *Monitoring of Solid Waste in Hong Kong 2003*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/ waste/data/waste_mon_swinhk.html> (26 June 2005).

HKEPD (2005a). *Environment Hong Kong 2005*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/ resources_pub/publications/pub_reports_ap.html> (26 June 2005).

HKEPD (2005b). *Monitoring of Solid Waste in Hong Kong 2004*. Environmental Protection Department (EPD), Hong Kong. <http://www.epd.gov.hk/epd/english/environmentinhk/waste/data/waste_mon_swinhk.html> (26 June 2005).

Escanciano, C., Fernandez, E., and Vazquez, C. (2002). Linking the firm's technological status and ISO 9000 certification: Results of an empirical research. *Technovation*, 22(8), 509–515.

ESRI (2004). *ArcGIS*. <http://www.esri.com/software/arcgis/about/overview.html>

European Commission (1999). *Integrating Environment Concerns into Development and Economic Cooperation*. Draft version 1.0, Brussels. Retrieved from European Environment Agency. <http://glossary.eea.eu.int/EEAGlossary/E/environmental_impact_assessment> (22 November 2001).

Farid, F., and Manoharan, S. (1996). Comparative analysis of resource-allocation capabilities of project management software packages. *Project Management Journal*, 35–44 June.

Fesseha, T. (1999). *Criteria for Selection of Demolition Techniques.* MSc Thesis, Loughborough University, Loughborough, UK.

FIDIC (1998). *Guide to ISO 14001 Certification/Registration* (Test edition). International Federation of Consulting Engineers (FIDIC), Switzerland.

Field, A. (2000). *Discovering Statistics Using SPSS for Windows*. SAGE Publications, London.

Fishbein, B.K. (1998). *Building for the Future: Strategies to Reduce Construction and Demolition Waste in Municipal Projects*. INFORM, Inc. <http://www.informinc.org/cdreport.html> (15 May 2002).

Frics, J.W. (1996). *Estimating for Building and Civil Engineering Works* (9th edition). Butterworth Heinemann Ltd, Oxford.

Gambatese, J.A., and James, D.E. (2001). Dust suppression using truck-mounted water spray system. *Journal of Construction Engineering and Management*, ASCE, 127(1), 53–59.

Gavilan, R.M., and Bernold, L.E. (1994). Source evaluation of solid waste in building construction. *Journal of Construction Engineering and Management*, ASCE, 120(3), 536–552.

Gidley, J.S., and Sack, W.A. (1984). Environmental aspects of waste utilization in construction. *Journal of Environmental Engineering*, ASCE, 110(6), 1117–1133.

Google (2005). Google Directory: Science > Software > Simulation.<http://directory.google.com/Top/Science/Software/Simulation/> (26 June 2005).

Griffith, A. (1994). *Environmental Management in Construction*. MacMillan Press Ltd, London.

Griffith, A., Stephenson, P., and Watson, P. (2000). *Management System for Construction*. Pearson Education Inc., New York and Englemere Ltd, England.

Grigg, N.S., Criswell, W.E., Fontane, D.G., and Siller, T.J. (2001). *Civil Engineering Practice in the Twenty-First Century: Knowledge and Skills for Design and Management*. ASCE Press, Reston, USA, 264 pp.

Griss, M., and Letsinger, R. (2000). Games at work – agent-mediated e-commerce simulation. In *HP Labs 2000 Technical Reports*. HP Labs, Hewlett-Packard Development Company, L.P. <http://www.hpl.hp.com/ techreports/2000/HPL-2000-52.html> (26 June 2005).

Grobler, F., Kannan, G., Subick, C., and Kargupta, H. (1995). Optimization of uncertain resource plans with GA. *Computing in Civil Engineering* (*1995*) (Proceedings of the Second Congress held in conjunction with A/E/C Systems '95 held in Atlanta, Georgia, 5–8 June 1995), ASCE, 1643–1650.

Guthrie, P., and Mallett, H. (1995). *Waste Minimization and Recycling in Construction: A Review*. Publication 122, CIRIA, London.

Hammad, A., Itoh, Y., and Nishido, T. (1993). Bridge planning using GIS and expert system approach, *Journal of Computing in Civil Engineering*, ASCE, 7(3), 278–295.

Hampton, T. (2004). 10 electronic technologies that changed construction (6/21/2004 Issue), ENR, The McGraw-Hill Companies, Inc. <http://enr.construction.com/features/technologyEconst/archives/040621.asp> (26 June 2005).

Harris, R. (1978). *Resource and Arrow Networking Techniques for Construction*. Wiley, New York.

HB (2000). *Hong Kong Fact Sheet – Housing (1999)*. Housing, Planning and Lands Bureau (HB), Hong Kong. <http://www.info.gov.hk/hkfacts/ housing.pdf> (26 June 2005).

Hegazy, T. (1999). Optimization of construction time-cost trade-off analysis using genetic algorithms. *Canada Journal of Civil Engineering*, NRC Canada, 26, 685–697.

Hegazy, T. (1999). Optimization of resource allocation and leveling using Genetic Algorithms. *Journal of Construction Engineering and Management*, ASCE, 125(3), 167–175.

Henderson, R.D. (1970). *Air Pollution and Construction Equipment*. SAE Earthmoving Industry Conference, Peoria, IL, 14–15, April. Paper 700551. 6.

Hendrickson, C., and Au, T. (2000). *Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders* (2nd edition). <http://www.ce.cmu.edu/pmbook/>(01/01/2006). 1st Edition printed by Prentice Hall, 1989.

Hendrickson, C., and Horvath, A. (2000). Resource use and environmental emissions of U.S. construction sectors. *Journal of Construction Engineering & Management*, ASCE, 126(1), 38–44.

Henningson, J.C. (1978). Environmental management during construction. *Journal of the Construction Division*. ASCE, 104(4), 479–485.

Hinckley, J.M. (1986). Reviewing for potential failure. *Civil Engineering*, ASCE, 56(7), 60–62.

HKEPD (2002). *The Directory of ISO 14001 Certified Companies in Hong Kong* (as at 2 April 2002). Hong Kong Environmental Protection Department (HKEPD), Hong Kong. <http://www.info.gov.hk/epd/english/how_help/tools_cem/iso14001.html> (1 July 2002).

HKPC (1996). HKPC Updates Local Businesses on ISO 14000 series and Environmental Management. *HKPC Productivity News*. Hong Kong Productivity Council (HKPC), Hong Kong, 55–56, October.

HKPC (2000). Press Release: *HKPC Organizes Industry Support Scheme on ISO 14001 Environmental Management System for Small and Medium Enterprises*. 22 February. Hong Kong Productivity Council (HKPC), Hong Kong. <http://www.hkpc.org/hkpc/html/newc_press_unit.asp?unit=4> (22 November 2001).

Ho, L. (1997). *Human Resources Planning Strategies of the Hong Kong Construction Industry*. Thesis of MBA. Department of Management, The Hong Kong Polytechnic University, Hong Kong.

Horvath, A., and Hendrickson, C. (1998). Steel versus steel-reinforced concrete bridges: environmental assessment. *Journal of Infrastructure Systems*, ASCE, 4(3), 111–117.

IAIA (1997). *Principles of Environmental Impact Assessment Best Practice*. International Association for Impact Assessment (IAIA). <http://www.iaia.org/principles/> (26 December 2002).

IDC (2004). *Business Simulations – Stimulating Business*. IDC Interact Ltd, Bristol, UK. <www.idcinteract.com>

ILS (2003). *Strategic E-Commerce Simulation*. Innovative Learning Solutions, Inc. (ILS). <http://www.marketplace-simulation.com/products/strategic-e-commerce.php> (26 June 2005).

Islam, M.S.P.E., and Hashmi, S.E.Q.P.E. (1999). Geotechnical aspects of foundation design and construction for pipelines buried in liquefiable riverbed. *Optimizing Post-Earthquake Lifeline System Reliability*: *Proceedings of the 5th U.S. Conference on Lifeline Earthquake Engineering*, ASCE, Seattle, WA, USA, 389–400.

ISO (The International Organization for Standardization) (2001). *ISO Survey of ISO 9000 and ISO 14000 series Certificates*. (Tenth cycle: up to and including 31 December 2000) <http://www.iso.org/iso/en/CombinedQueryResult.CombinedQueryResult?queryString=Survey> (4 June 2002).

ISO (2002). *ISO 9000 and ISO 14000 Certifications Reach Record Levels in 2001*. The International Organization for Standardization (ISO). 19 July 2002. Ref.: 830. <http://www.iso.org/> (26 December 2002).

Issa, R.R.A. (1995). A pen-centric application for construction quality and Productivity Tracking. In J.P. Mohsen (Editor), *Computing in Civil Engineering* (Proceedings of the Second Congress held in conjunction with A/E/C Systems '95 held in Atlanta, Georgia, June 5–8, 1995), ASCE, New York, 1356–1359.

Jeljeli, M.N., and Russell, J.S. (1995). Coping with uncertainty in environmental construction: decision-analysis approach. *Journal of Construction Engineering and Management*, ASCE, 121(4), 370–380.

Jeljeli, M.N., Russell, J.S., Meyer, H.W.G., and Vonderohe, A.P. (1993). Potential applications of geographic information systems to construction industry. *Journal of Construction Engineering and Management*, ASCE, 119(1), 72–86.

Jones, K.H. (1973). Synthesis approach to determining research needs in civil engineering. *Journal of the Environmental Engineering Division*, ASCE, 99(4), 461–467.

Jones, N., and Klassen, R.D. (2001). Management of pollution prevention: Integrating environmental technologies in manufacturing. In *Greener Manufacturing and Operations: From Design to Delivery and Back*. Edited by J. Sarkis, J. Greenleaf Publishing Ltd. Sheffield, UK, 56–68.

Kasai, Y. (ed.) (1998). Demolition and reuse of concrete and masonry: Demolition methods and practice. *Proceedings of the Second International Symposium*. Held by RILEM (the International Union of Testing and Research Laboratories for Materials and Structures), Nihon Daigaku Kaikan, Tokyo. November 7–11, 1988. Chapman and Hall, London.

Kawal, D.E. (1971). Information utilization in project planning. *Journal of the Construction Engineering Division*, ASCE, 97(2), 227–240.

Kein, A.T.T., Ofori, G., and Briffett, C. (1999). ISO 14000 series: Its relevance to the construction industry of Singapore and its potential as the next industry milestone. *Construction Management and Economics*, 17(4), 449–461.

Kemme, M.R. (1998). *Barcode Tracking System for Hazardous Waste* (HW). Construction Engineering Research Laboratory, U.S. Army Corps of Engineers, Champaign, IL, USA. <http://www.cecer.army.mil/td/tips/product/details.cfm?ID=25&TOP=1> (26 June 2005).

Kennedy, M. (2002). *The Global Positioning System and GIS: An Introduction*. Taylor & Francis, London.

Khalfan, M.M.A., Bouchlaghem, N.M., Anumba, C.J., and Carrillo, P.M. (2003). Knowledge management for sustainable construction: The C-SanD Project. In Molenaar, K.R. and Chinowsky, P.S. (Eds), *Winds of Change: Integration and Innovation in Construction (Proceedings of the 2003 Construction Research Congress)*, Honolulu, Hawaii, 19–21 March 2003. Reston: American Society of Civil Engineers.

Khasnabis, S., Alsaidi, E., Liu, L., and Ellis, R.D. (2002). Comparative study of two techniques of transit performance assessment. *Journal of Transportation Engineering*, ASCE, 128(6), 499–508.

Kincaid, J.E., Walker, C., and Flynn, G. (1995). *WasteSpec: Model Specifications for Construction Waste Reduction, Reuse, and Recycling*. Triangle J Council of Governments. P.O. Box 12276, Research Triangle Park NC 27709, USA. <http://www.tjcog.dst.nc.us/cdwaste.htm#wastespec> (26 June 2005).

Kloepfer, R.J. (1997). Will the real ISO 14001 please stand up. *Civil Engineering*, ASCE, 67(11), 45–47.

Koehn, E. (1976). Social and environmental costs in construction. *Journal of the Construction Division*, ASCE, 102(4), 593–597.

Lais, S. (1999). *Building Industry Braces for IT*, Online Onslaught, Computerworld Inc. <http://www.computerworld.com/cwi/story/frame/0,1213,NAV47_STO36776,00.html>.

Landscape Institute with IEMA (Institute of Environmental Management and Assessment) (2002). *Guidelines for Landscape and Visual Impact Assessment* (2nd edition). Spon Press, New York.

Laufer, A., and Jenkins, G.D. (1982). Motivating construction workers. *Journal of the Construction Division*, ASCE, 108(4), 531–545.

Launen, K.J. (1993). GPS – rapid solutions for transportation management, *Journal of Surveying Engineering*, ASCE, 119(1), 40–49.

Lavers, A.P., and Shiers, D.E. (2000). Construction law and environmental harm: The liability interface. *Construction Management and Economics*, Spon Press, 18(8), 893–902.

Leu, S., and Yang, C. (1999). GA-based multicriteria optimal model for construction scheduling. *Journal of Construction Engineering and Management*, ASCE, 125(6), 420–427.

Leu, S.S., Chen, A.T., and Yang, C.H. (1999). Fuzzy optimal model for resource-constrained construction scheduling. *Journal of Computing in Civil Engineering*, ASCE, 13(3), 207–216.

Leung, W.O. (1999). Effluent control for the construction projects. *Proceedings of International Conference on Urban Pollution Control Technology*, The Hong Kong Polytechnic University, Hong Kong, 449–455.

Li, H., and Love, P.E.D. (1997). Using improved genetic algorithms to facilitate time-cost optimization. *Journal of Construction Engineering and Management*, ASCE, 123(3), 233–237.

Li, H., Cao, J.N., and Love, P.E.D. (1999). Using machine learning and GA to solve time-cost trade-off problems. *Journal of Construction Engineering and Management*. ASCE, 125(5), 347–353.

Li, H., Chen, Z., and Wong, C.T.C., and Love, P.E.D. (2002). A quantitative approach to construction pollution control based on resource leveling. *International Journal of Construction Innovation*, 2(2), 71–81.

Li, H., Kong, C.W., Pang, Y.C., Shi, W.Z., and Yu, L. (2003a). Internet-based geographical information systems for e-commerce application in construction material procurement, *Journal of Construction Engineering and Management*, ASCE, 129(6), 689–697.

Li, H., Chen, Z., and Wong, C.T.C. (2003b). Application of barcode technology for an incentive reward program to reduce construction wastes in Hong Kong. *Computer-Aided Civil and Infrastructure Engineering*, 18(4), 313–324.

Lippiatt, B.C. (1999). Selecting cost-effective green building products: BEES approach. *Journal of Construction Engineering and Management*, ASCE, 125(6), 448–455.

Liska, R.W., and Snell, B. (1993). Financial incentive programs for average-size construction firm. *Journal of Construction Engineering and Management*, ASCE, 118(4), 667–676.

Lo, C.H. (2001). *Critical Factors for the Implementation of ISO 14001 Environmental Management System in Hong Kong Construction Industry*. M.Sc. Thesis. The Hong Kong Polytechnic University, Hong Kong.

Love, P.E.D., and Li, H. (2000). Quantifying the causes and cost of rework. *Construction Management and Economics*, 18(4), 479–490.

Lundberg, E.J., and Beliveau, Y.J. (1989). Automated lay-down yard control system-ALYC. *Journal of Construction Engineering and Management*, ASCE, 115(4), 535–544.

Maitra, A. (1999). Designers under CDM: A discussion with case studies. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, 132(5), 77–84.

Mark, R. (2000). *IDC Online Previews New Portal*. Jupitermedia Corporation. <http://dc.internet.com/news/article.php/2101_389961> (26 June 2005).

Maslow, A.H., Stephens, D.C., and Heil, G. (1998). *Maslow on Management*. John Wiley, New York.

Masters, N. (2001). *Sustainable Use of New and Recycled Materials in Coastal and Fluvial Construction: A Guidance Manual*, Thomas Telford, London.

McCullouch, B.G., and Lueprasert, K. (1994). 2D bar-code applications in construction. *Journal of Construction Engineering and Management*, ASCE, 120(4), 739–753.

McCullough, C.A., and Nicklen, R.R. (1971). Control of water pollution during dam construction. *Journal of the Sanitary Engineering Division*, ASCE, 97(1), 81–89.

McFall, K. (2004). Delivering on promises (2/16/2004 Issue), ENR, The McGraw-Hill Companies, Inc. <http://enr.construction.com/features/technologyEconst/archives/040216.asp> (26 June 2005).

McMullan, R. (1998). *Environmental Science in Building* (4th edition). Macmillan, Basingstoke, England.

Meade, L.M., and Sarkis, J. (1999). Analyzing organizational project alternatives for agile manufacturing processes. *International Journal of Production Research*, Institution of Production Engineers, London, 37(2), 241–261.

Merchant, K.A. (1997). *Modern Management Control Systems: Text and Cases*. Prentice-Hall, Inc., New Jersey, USA.

Metcalf, D.D., and Urban, M.R. (1992). Leveraging the use of geographic information systems in highway corridor studies. In B.J. Goodno, J.R. Wright (Editors), *Computing in Civil Engineering and Geographic Information Systems Symposium* (Proceedings of the Eighth Technical Council on Computer Practices Conference held in conjunction with A/E/C Systems '92), ASCE, New York, 174–181.

Metro (1997). Construction site recycling-save money by recycling. <http:// www.metro-waste.com/commercial/construction.htm>, <http://www. multnomah.lib.or.us/metro/rem/rwp/constrcy.html> (2000/2003).

MFE (2004). Construction and demolition waste. Ministry for the Environment (MFE), New Zealand. <http://www.mfe.govt.nz/issues/waste/construction-demo/> (26 June 2005).

Middleton, F.M. and Stenburg, R.L. (1972). Research needs for advanced waste treatment. *Journal of the Sanitary Engineering Division*, 98(3), 515–528.

Mifkovic, C.S., and Peterson, M.S. (1975). Environmental aspects: Sacramento bank protection. *Journal of the Hydraulics Division*, ASCE, 101(5), 543–555.

Miller, R. (1999). *Demolition*. <http://www.fbe.unsw.edu.au/subjects/bldg/3005/demolition/ index.htm> (1 February 2001).

Mingpao.com (28 May 2002). *Transporters Allowed Free Disposal*, Mingpao, Hong Kong. <http://www.mingpao.com> (2 August 2002).

MOC (2001a). Announcement of First Authorized Qualifications of Main Contractors or Specialized Contractors with Special grade or Grade 1. Ministry of Construction (MOC), China. <http://zj.civil-engrg.com/ fg/show.asp?id=69> (22 March 2001).

MOC (2001b). Prescription for Qualification Management of Construction Enterprises. Prescription No. 87 of MOC. Beijing. Ministry of Construction (MOC), China. <http://www.cein.gov.cn/ad/d_1.htm,> <http://www.cin.gov.cn/indus/notice/2001072701.htm> and <http://www.cein.gov.cn/show.asp?rec_no=2590> (22 March 2001).

MOC (2001c). *Standard Grade of Main Building Contractors*, Ministry of Construction (MOC), China. <http://www.cein.gov.cn/ zznj/stepbystep/govfile/sgzcb.html> (22 March 2001).

Mohr, A.W. (1975). Energy and pollution concerns in Dredging. *Journal of the Waterways Harbors and Coastal Engineering Division*, ASCE, 101(4), 405–417.

Morris, D. (1976). Seasonal effects on building construction. *Journal of the Construction Division*, ASCE, 102(1), 29–39.

Morris, S.C., and Novak, E.W. (1976). Environmental health impact assessment. *Journal of the Environmental Engineering Division*, ASCE, 102(3), 549–554.

Mueller, I. *et al.* (1975). Waste exchange as a solution to industrial waste problems. *Israel Journal of Chemistry (ISJCAT Journal)*, 14, 226–233.

MWA (2000). *Commercial Programs – Construction and Demolition*, Metro Waste Authority (MWA), Des Moines, Iowa, USA. <http://www.metro-waste.com/commercial/construction.htm>, <http://www.multnomah.lib.or.us/metro/rem/rwp/ constrcy.html>.

NAHB Research Center (1999). *Guide to Developing Green Builder Programs*, A Report by the NAHB Research Center for the U.S. Environmental Protection Agency. <http://www.smartgrowth.org/pdf/Greengd.pdf> (12 June 2002).

Naresh, A.L., and Jahren, C.T. (1997). Communications and Tracking for Construction Vehicles, *Journal of Construction Engineering and Management*, ASCE, 123(3), 261–268.

Nasland, D.K., and Johnson, D.P. (1996). Real-time construction staking, *Civil Engineering*, ASCE, 66(6), 46–49.

Nelson, B. (1994). *1001 Ways to Reward Employees*, Workman, New York.

NOIE (2001). *B2B E-Commerce: Capturing Value Online*. National Office for the Information Economy (NOIE), Australia. <http://www.noie.gov.au/publications/NOIE/B2B/index.htm> (20 August 2002).

Norusis, M.J. (2000). *SPSS 10.0 Guide to Data Analysis*, Prentice-Hall, Inc., USA.

NPPA (1993). *Noise Pollution and Protection Act*, The People's Republic of China. Governmental Document in Chinese.

Ofori, G., Briffett, C., Gang, G., and Ranasinghe, M. (2000). Impact of ISO 14000 series on construction enterprises in Singapore. *Construction Management and Economics*, 18(8), 935–947.

OGC (2004). *Implementing Plans: Checklist of Organisational Learning and Maturity*. OGC Successful Delivery Toolkit™, The Office of Government Commerce (OGC), UK. <http://www.ogc.gov.uk/sdtoolkit/reference/tools/ip_positioning.html> (26 June 2005).

Olomolaiye, P.O., Jayawardane, A.K.W., and Harris, F.C. (1998). *Construction Productivity Management*, The Chartered Institute of Building. Addison Wesley Longman Limited, UK.

Orofino, J.F. (editor) (1989). *Structural Materials: Proceedings of the Sessions Related to Structural Materials at Structures Congress '89*, ASCE, New York.

Osuagwu, L. (2002). TQM strategies in a developing economy: Empirical evidence from Nigerian companies. *Business Process Management Journal*, MCB UP Ltd. 8(2), 140–160.

Parker, T. (1998). *Total Cost Indicators: Operational Performance Indicators for Managing Environmental Efficiency*, IIIEE Dissertations, the International Institute for Industrial Environmental Economics at Lund University, Sweden.

Parker, D.G., and Stader, T.N. (1995). Use of GIS to predict erosion in construction. In W.H. Espey, P.G. Combs (Editors), *Water Resources Engineering* (Proceedings of the First International Conference held in San Antonio, TX, 14–18 August 1995), New York: ASCE, 839–843.

Petts, J. (1996). *Environmental Assessment: Good Practice*. Proceedings of the Construction Industry Environmental Forum Conference on Good Practice in Environmental Assessment, Publication SP126, CIRIA, London.

Peurifoy, R.L. (2002). *Construction Planning, Equipment, and Methods* (6th edition), McGraw-Hill, New York.

Peyton, T.L. (1977). Energy management in commercial buildings. *Journal of Professional Activities*, ASCE, 103(1), 31–35.

Pilcher, R. (1992). *Principles of Construction Management* (3rd edition), McGraw-Hill, UK.

PIPS (2001). *Scanners and Data Collection Terminals*. Product Identification and Processing System (PIPS) Inc., New York, USA. <http://www.pips.com/scanners.html> (May 15, 2002).

PlanWare (2004). *Business Insight – Business Strategy Evaluator*, Invest-Tech Ltd. <http://www.planware.org/>

Poon, C.S., and Ng, L.H. (1999). The use of modern building technologies for waste minimization in Hong Kong. *Proceeding of International Conference on Urban Pollution Control Technology* (eds. C.S. Poon, X.Z. Li,). Hong Kong Polytechnic University, Hong Kong, 413–419.

Poon, C.S., Xu, Y., and Cheung, C.M. (1996). Building waste minimization in Hong Kong construction industry, *Journal of Solid Waste Technology and Management*, 23(2), 111–117.

Poon, C.S., Yu, A.T.W., and Ng, L.H. (2001). On-site sorting of construction and demolition waste in Hong Kong. *Resources, Conservation & Recycling*, 32(1), 157–172.

Proverbs, D.G., Holt, G.D., and Olomolaiye, P.O. (1998). A comparative evaluation of reinforcement fixing productivity rates amongst French, German and UK construction contractors. *Engineering, Construction and Architectural Management*, 5(4), 350–358.

Quazi, H.A., Khoo, Y.K., Tan, C.M., and Wong P.S. (2001). Motivation for ISO 14000 series Certification: Development of an evaluation model, *Omega: The International Journal of Management Science*. 29(6), 525–542.

Rappa, M. (2002). *Managing the Digital Enterprise*, Open Courseware. North Carolina State University. Raleigh, North Carolina, USA.

Rasdorf, W.J., and Herbert, M.J. (1989). Barcodes on the job site. *ID Systems*, 9(3), 32–36.

Rasdorf, W.J., and Herbert, M.J. (1990a). Automated identification systems-focus on bar coding. *Journal of Computing in Civil Engineering*, 4(3), 279–296.

Rasdorf, W.J., and Herbert, M.J. (1990b). Bar coding in construction engineering. *Journal of Construction Engineering and Management*, 116(2), 261–280.

Reardon, D.J. (1995). Turning down the power. *Civil Engineering*, ASCE, 65(8), 54–56.

Reddy, B.V.V., and Jagadish, K.S. (2003). Embodied energy of common and alternative building materials and technologies. *Energy and Buildings*, 35(2), 129–137.

Reeves, C.R. (1993). *Modern Heuristic Techniques for Combinatorial Problems*. Blackwell Scientific Publications, Oxford, Halsted Press, New York.

Rhatigan, J., and Irwin, D. (2001). *Salvage Style: 45 Home and Garden Projects using Reclaimed Architectural Details*, Lark Books, New York, N.Y. USA.

Robinson, S. (1994). *Successful Simulation: A Practical Approach to Simulation Projects*, McGraw-Hill, Maidenhead, England.

Robinson, G.L., Greening, W.J.T., DeKrom, P.W., Chrzanowdki, A., Silver, E.C., Allen, G.C., and Falk, M. (1995). Surface and underground geodetic control for superconducting super collider. *Journal of Surveying Engineering*, ASCE, 121(1), 13–34.

Rollett, H. (2003). *Knowledge Management: Processes and Technologies*, Kluwer Academic Publishers, Boston, USA.

Rosenfeld, Y., and Shapira, A. (1998). Automation of existing tower cranes: Economic and technological feasibility. *Automation in Construction*, Elsevier Science Inc., 7(4), 285–298.

Rosowsky, D.V. (2002). Reliability-based seismic design of wood shear walls. *Journal of Structural Engineering*, ASCE, 128(11), 1439–1453.

Ross, S., and Evans, D. (2003). The environmental effect of reusing and recycling a plastic-based packaging system. *Journal of Cleaner Production*, 11(5), 561–571.

Rutherford, J. (1981). On-site stormwater detention ponds: Wet and dry. In *Surface Water Impoundments: Proceedings of Symposium on Surface Water Impoundments* (1980: Minneapolis, Minn.). Edited by H.G. Stefan, ASCE, 972–984.

Saaty, T.L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process*, Pittsburgh, PA, USA: RWS Publications.

Saaty, T.L. (1999). Fundamentals of the ANP. *ISAHP Proceedings*, Kobe, Japan. 16.

Saaty, T.L. (2001). Decision-making with the AHP: Why is the principal eigenvector necessary. *Proceedings of ISAHP 2001*, Berne, Switzerland.

Sacks, R., Navon, R., and Goldschmidt, E. (2003). Building project model support for automated labor monitoring. *Journal of Computing in Civil Engineering*, ASCE, 17(1), 19–27.

Sailor, V.L. (1974). Conservation of energy in buildings. *Journal of the Construction Division*, ASCE, 100(3), 295–302.

Salomon, V.A.P., and Montevechi, J.A.B. (2001). A compilation of comparisons on the analytic hierarchy process and other multiple criteria decision making methods: Some cases developed in Brazil. *Proceedings of 6th ISAHP*, Berne, Switzerland, 2–4 August 2001, 413–419.

SAP INFO (2004). *SAP INFO glossary*. <http://www.sap.info/public/en/glossary.php4/displayglossarystart> (18 November 2004).

Sauni, R., Oksa, P., Vattulainen, K., Uitti, J., Palmroos, P., and Roto, P. (2001). The effects of asthma on the quality of life and employment of construction workers. *Occupational Medicine*, Oxford University Press, 51(3), 163–167.

Sawhney, A., Mund, A., and Syal, M. (2002). Energy-efficiency strategies for construction of five star plus homes. *Practice Periodical on Structural Design and Construction*, ASCE, 7(4), 174–181.

SC of China (1998). *Managerial Ordinance on Environmental Protection of Construction Project*, The State Council of People's Republic of China. <http://www.envir.online.sh.cn/law/const2.htm> (22 November 2001).

Schodek, D.L. (1976). Effect of building regulations on built environment. *Journal of Professional Activities*, ASCE, 102(3), 293–300.

Schuette, S.D., and Liska, R.W. (1994). *Building Construction Estimating*. McGraw-Hill, Inc., New York.

Selwood, J.R., and Whiteside, P.G.D. (1992). Use of GIS for resource management in Hong Kong, In B.J. Goodno, and J.R. Wright (Editors), *Computing in Civil Engineering and Geographic Information Systems Symposium* (Proceedings of the Eighth Technical Council on Computer Practices Conference held in conjunction with A/E/C Systems '92), ASCE, New York, 942–949.

Senouci, A.B., and Adeli, H. (2001). Resource scheduling using neural dynamics model of Adeli and Park. *Journal of Construction Engineering and Management*, ASCE, 127(1), 28–34.

Seo, S., and Hwang, Y. (1999). An estimation of construction and demolition debris in Seoul, Korea: Waste amount, type, and estimation model. *Journal of the Air & Waste Management Association*, 49(8), 980–985.

Shorrock, L., *et al.* (1993). *Environmental Issues in Construction – A Review of Issues and Initiatives Relevant to the Building, Construction and Related Industries. Volume 1 – Overview Including Executive and Technical Summaries*. Publication SP93. CIRIA, UK.

Skibniewski, M.J., and Wooldridge, S.C. (1992). Robotic materials handling for automated building construction technology. *Automation in Construction*, 1(3), 251–266.

Skoyles, J.R. (1992). An approach to reducing materials waste on site. *The Practice of Site Management* (*Volume 4*) (*Ed.* Harlow, P.A.) The Chartered Institute of Building. Englemere, UK.

Skoyles, E.R., and Hussey, H.J. (1974). Wastage of materials. *Building*. 95–100 February.

Sparks, P.R., Liu, H., and Saffir, H.S. (1989). Wind damage to masonry buildings. *Journal of Aerospace Engineering*, ASCE, 2(4), 186–198.

Spivey, D.A. (1974a). Construction solid waste. *Journal of the Construction Division*, ASCE, 100(4), 501–506.

Spivey, D.A. (1974b). Environment and construction management engineers. *Journal of the Construction Division*, ASCE, 100(3), 395–401.

Srisoepardani, K.P. (1996). *The Possibility Theorem for Group Decision Making: The Analytic Hierarchy Process*, PhD Dissertation. Katz Graduate School of Business, University of Pittsburgh, Pittsburgh, Pennsylvania, USA.

Stanley-Miller Construction Company (1996). Case studies: ToolWatch® shines light on thieves: Stolen equipment recovered for Ohio Construction Company. <http://www.toolwatch.com/toolwatch/casestudies/Stanley.php> (15 May 2002).

Stone, P.A. (1983). *Building Economy* (3rd edition), Pergamon Press, England.

Stukhart, G. (1995). *Construction Materials Management*, Marcel Dekker, Inc., New York.

Stukhart, G., and Cook, E.L. (1989). *Barcode System Standardization in Industrial Construction*, Source Document 47, Construction Industry Institute. USA.

Stukhart, G., and Cook, E.L. (1990). Barcode standardization in industrial construction. *Journal of Construction Engineering and Management*, ASCE, 116(3), 416–431.

Stukhart, G., and Nomani, A. (1992). *Barcode System Standardization*, Source Document 70, Construction Industry Institute. USA.

Stukhart, G., and Pearce, S.L. (1988). Construction barcode standards. *Proceedings of fifth International Symposium in Robotics in Construction*, Japanese Society of Civil Engineers, 361–370.

Stukhart, G., and Pearce, S.L. (1989). Construction barcode standards. *Cost Engineering*, 31(6), 19–26.

Sukut (2003). *Unique Technologies Sukut has Implemented*. Sukut Construction, Inc., Santa Ana, USA. <http://www.sukut.com/# Anchor-Press-44097> (26 June 2005).

Suprenant, B.A. (Editor) (1990). *Serviceability and Durability of Construction Materials: Proceedings of the First Materials Engineering Congress*, ASCE, Denver, Colorado, USA.

Suprenant, B.A., and Malisch, W.R. (2000). The cost of waiting. *Concrete Construction*, Hanley-Wood, LLC, June 2000, 59–61.

Swain, J. (2001). Simulation software survey. *OR/MS Today*. February 2001 Issue. <http://www.lionhrtpub.com/orms/surveys/Simulation/Simulation.html> (26 June 2005).

Syswerda, G., and Palmucci, J. (1991). The application of genetic algorithms to resource scheduling. *Proceedings of the Fourth International Conference on Genetic Algorithms*. (Edited by R.K. Belew, and L.B. Booker), Morgan Kaufmann Publishers, San Mateo, California, USA. 502–507.

Tatum, C.B. (1978). Managing nuclear construction: an experience survey. *Journal of the Construction Division*, ASCE, 104(4), 487–501.

Taylor, D.C., Wilkinson, M.C., and Kellogg, J.C. (1976). A construction industry R&D incentives program. *Journal of Professional Activities*, ASCE, 102(3), 369–390.

Thomas, H.R., Sanders, S.R., and Bilal, S. (1992). Comparison of labor productivity. *Journal of Construction Engineering and Management*, ASCE, 118(4), 635–650.

Thomas, H.R., Sanvido, V.E., and Sanders, S.R. (1990). Impact of material management on productivity – a case study. *Journal of Construction Engineering and Management*, ASCE, 115(3), 370–384.

Tian, Q. (2002). *CMSS: An Interactive Construction Management Simulation System*, MASc Dissertation, Graduate Department of Civil Engineering, University of Toronto, Canada.

Tiwari, P. (2001). Energy tax and choice of house construction techniques in India. *Journal of Infrastructure Systems*, ASCE, 7(3), 107–115.

Trimble (2004). Mapping and GIS. <http://www.trimble.com/mgis.shtml> (30 June 2005).

Tse, R. (2001). The implementation of EMS in construction firms: Case study in Hong Kong. *Journal of Environmental Assessment Policy and Management (JEAPM)*, 3(2), 177–194.

Turban, E., King, D., Lee, J.K., and Viehland, D. (2003). *Electronic Commerce 2004: A Managerial Perspective* (3rd edition), Prentice Hall, USA.

Udo-Inyang, P.D., and Uzoije, C.H. (1997). HICIMS: An integrated GIS and DBMS application, In T.M. Adams (Ed.) *Computing in Civil Engineering* (Proceedings of the Fourth Congress held in conjuction with A/E/C Systems '97 in Philadelphia, PA, June 16–18, 1997), New York: ASCE, 240–247.

UNMFS (2004). Performance indicators for the evaluation of business plans, in *Multilateral Fund for the Implementation of the Montreal Protocol: Policies, Procedures, Guidelines and Criteria*. The Secretariat of the Multilateral Fund for the Implementation of the Montreal Protocol, Canada. <http://www.multilateralfund.org/policy.htm> (2004).

Uren, S., and Griffiths, E. (2000). *Environmental Management in Construction*, Publication C533, CIRIA, London, UK.

USEPA (1971). *Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances*, Environmental Protection Agency, Washington, D.C., USA.

USEPA (1973). *Processes, Procedures, and Methods to Control Pollution Resulting from all Construction Activity*, Environmental Protection Agency, USA.

USEPA (2002a). EPA releases diesel exhaust health assessment. EPA Press Releases related to the Office of Transportation and Air Quality (OTAQ) for 2002. <http://www.epa.gov/otaq/press.htm> (30 September 2002).

USEPA (2002b). *Health Assessment Document for Diesel Engine Exhaust*. Prepared by the National Center for Environmental Assessment, Washington, DC, for the Office of Transportation and Air Quality; EPA/600/8-90/057F. Available from: National Technical Information Service, Springfield, VA; PB2002-107661. <http://www.epa.gov/ncea> (30 September 2002).

USEPA (2002c). Emission standards for new nonroad engines: Large industrial spark-ignition engines, recreational marine diesel engines, and recreational vehicles. Prepared by the National Center for Environmental Assessment, Washington, DC, for the Office of Transportation and Air Quality; EPA420-F-02-037. Available from: National Technical Information Service, Springfield, VA; PB2002-107661. <http://www.epa.gov/otaq/regs/nonroad/2002/f02037.pdf> (30 September 2002).

Vaid, K.N., and Tanna, A. (1997). *Wastage Control of Building Materials in Construction of Mass Housing Projects*, National Institute of Construction Management and Research (NICMAR), India, 1997, 19–35.

Valdez, H.E., and Chini, A.R. (2002). ISO 14000 standards and the US construction industry. *Environmental Practice*, 4(4), 210–219.

Varghese, K., and O'Connor, J.T. (1995). Routing large vehicles on industrial construction sites. *Journal of Construction Engineering and Management*, ASCE, 121(1), 1–12.

Velker, L. (1999). Caution: KM under construction – challenges and solutions from a geographically diverse contractor. *KMWorld Magazine*, 8(5).

Walter, C.E. (1976). Practical refuse recycling. *Journal of the Environmental Engineering Division*, ASCE, 102(1), 139–148.

Warren, F.H. (1973). Environmental impact on project schedules. *Journal of Professional Activities*, ASCE, 99(3), 299–306.

Warren, R.H. (1989). *Motivation and Productivity in the Construction Industry*, Van Nostrand Reinhold, New York.

Waugh, L.M., and Makar, J. (2001). *The Impact of e-commerce on the Construction Industry*. Presented at the international symposium Construction Innovation: Opportunities for Better Value and Profitability, June 6–7, 2001.

Wiegele, E. (2000). New construction methodologies using GIS, GPS, and the Web, *GITA's 9th Annual GIS for Oil & Gas Conference and Exhibition*, September 18–20–2000, in Houston, Texas, USA. <http://www.gisdevelopment.net/proceedings/gita/oil_gas2000/papers/wiegele.shtml> (30 June 2005).

Williams, J.W. (1992). Integrated GIS solutions with civil engineering projects, In B.J. Goodno, J.R. Wright (Editors), *Computing in Civil Engineering and Geographic Information Systems Symposium* (Proceedings of the Eighth Technical Council on Computer Practices Conference held in conjunction with A/E/C Systems '92), ASCE, New York, 328–331.

Wirt, D., Showalter, W.E., and Crouch, G. (1999). Integrating permanent equipment tracking with electronic operations and maintenance manuals. *Durability of Building Materials and Components 8 (Volume Four): Information Technology in Construction.* (Edited by M.A. Lacasse, D.J. Vanier) (CIB W78 Workshop) NRC Research Press, Ottawa, Canada, 2716–2723.

Wong, O., Morgan, R.W., and Kheifets, L. *et al.* (1985). Mortality among members of a heavy construction equipment operators union with potential exposure to diesel exhaust emissions. *British Journal of Industrial Medicine*, 42, 435–448.

WRC (2000). *Annual Review of Implementation of the Waste Reduction Framework Plan*, Waste Reduction Committee (WRC), Hong Kong. <http://www.info.gov.hk/wrc/>.

Zarli, A., Rezgui, Y., and Kazi, A.S. (2003). Present and future of European research on information technologies in construction. In Molenaar, K.R. and Chinowsky, P.S. (Eds), *Winds of Change: Integration and Innovation in Construction* (Proceedings of the 2003 Construction Research Congress, Honolulu, Hawaii, March 19–21, 2003). Reston: American Society of Civil Engineers.

Zeeger, C.V., and Rizenbergs, R.L. (1979). Priority programming for highway reconstruction. *Transportation Research Record*, No. 698, 15–23.

Zeng, S.X., Tam, C.M., Deng, Z.M., and Tam, Vivian W.Y. (2003). ISO 14000 and the construction industry: Survey in China. *Journal of Management in Engineering*, ASCE, 19(3), 107–115.

Zhu, Z. (1996). *Handbook of Building Construction Estimator*, China Construction Industry Press. Beijing, China.

Zutshi, A., and Sohal, A. (2004a). Environmental management system adoption by Australasian organisations: part 1: reasons, benefits and impediments. *Technovation*, 24(4), 335–357.

Zutshi, A., and Sohal, A. (2004b). A study of the environmental management system (EMS) adoption process within Australasian organizations: part 2: Role of stakeholders. *Technovation*, 24(5), 371–386.

Zyngier, S.M. (2002). Knowledge management strategies in Australia: Preliminary results of the survey of the knowledge management uptake in Australian companies. Caulfield East, Vic.: School of Information Management and Systems, Monash University, Australia.

Collateral readings

BRE (1994). *Embodied Energy of Building Materials*. Building Research Establishment (BRE), UK. <http://www.ecosite.co.uk/depart/backinfo/bldmat.htm> (27 March 2003).

BRECSU (1996). *A Strategic Approach to Energy and Environmental Management*, Building Research Establishment. Garston, Watford, UK.

Bruhn-Tysk, S., and Eklund, M. (2002). Environmental impact assessment – a tool for sustainable development? A case study of biofuelled energy plants in Sweden. *Environmental Impact Assessment Review*, 22(2), 129–144.

Catterson, D. (1997). *The Reusable Building Materials Exchange: A New Approach to an Old Problem*. <http://www.olywa.net/speech/august97/catterson.html> (2000/2003).

CEIN (1998). *Main Indicators on Construction Enterprises*. <http://www.cein.gov.cn/home/hytj/jzyhytj/1998/14-8.doc> (22 November 2001).

CEIN (2001b). *The 10th Five-year Plan Opening Big Commercial Opportunity to Foreign Companies*. China Engineering Information Net (CEIN), China. <http://www.cein.gov.cn/show.asp?rec_no=577> (22 November 2001).

China EPB (1999). *Official Report on the State of the Environment in China 1998*. Environmental Protection Bureau (EPB), China. <http://www.zhb.gov.cn/bulletin/soechina98/index.htm> (22 November 2001).

China EPB (2001a). *Official Report on the State of the Environment in China 2000*. Environmental Protection Bureau (EPB), China. <http://www.zhb.gov.cn/bulletin/soe2000/index.htm> (10 June 2002).

China EPB (2001b). An Assessment Report on Integrated Environmental Governance in Forty-six Main Cities in China. Official Document of China EPB, No. (2001) 84. Environmental Protection Bureau (EPB), China. <http://www.zhb.gov.cn/sepa/news/200108/ hb84.htm> (5 June 2002).

China EPB (2001c, November 22). Conditions on Establishment of National Demonstration District based on ISO 14000 series. *The China Environment Daily*. Environmental Protection Bureau (EPB), China. <http://www.envir.online.sh.cn/info/2001/11/1122041.htm> (22 November 2001).

China NBS (1999). *Statistical Yearbook of China 1998*. National Bureau of Statistics (NBS), China. <http://www.stats.gov.cn/sjjw/ndsj/information/nj98/ml98.htm> (22 November 2001).

China NBS (2002). *China Statistic Yearbook (1995–2000)*. National Bureau of Statistics (NBS), China. <http://www.stats.gov.cn/tjsj/ndsj/index.htm> (25 June 2002).

CIIC (2001). *China in Brief: Administrative Division*. Internet Information Center, China. <http://www.china.org.cn/e-china/administrative/cities.htm> (22 November 2001).

CIRIA (2002). *Internet Scheme to Save on Waste*. CIRIA News. Issue 2, 8.

Clemen, R.T., and Reilly, T. (2001). *Making Hard Decisions with Decision Tools®*. Duxbury, Thomson Learning, USA.

CNPlus.co.uk (2002). *E-Construction Yearbook: Internet Services and Software for the UK Construction Industry*. EMAP. <http://www.cnplus.co.uk/econstruction/?ChannelID=62> (26 June 2005).

CSD (1984/2003). *Report on Annual Survey of Building, Construction and Real Estate Sectors*. Census and Statistics Department (CSD), Hong Kong.

ERM-Hong Kong, Ltd (1996). *Waste Reduction Study: Consultants' Findings and Recommendations*. EPD Waste Reduction Study (C1421). Environmental Protection Department (EPD), Hong Kong.

Green, S.B., Salkind, N.J., and Akey, T.M. (2000). *Using SPSS for Windows: Analyzing and Understanding Data* (2nd edition). Prentice-Hall Inc., Upper Saddle River, NJ, USA.

Horton Engineering (2001). *Horton Engineering Internet Calculators: Geometric Mean Calculator*. <http://www.graftacs.com/geohelp.html> (22 November 2001).

HPB (2000). *A Memorandum about Onerous Service on Disposal of Construction Waste*. Hefei Price Bureau (HPB), Anhui Province, China. <http://www.hfsr.gov.cn/fg5.htm> (22 November 2001).

Huang, Y.P. (2001). Fifteen hills of construction wastes on road. *Xian Evening Daily*. <http://cn.news.yahoo.com/ 011117/15/t3xc.html> (17 November 2001).

JACIC (2002). Construction by-products information exchange system and service. *JACIC News*. No. 156. May 2002. Japan Construction Information Center, Japan. <http://www.jacic.or.jp/books/jacicnews/jn156.pdf> and <http://www.recycle.jacic.or.jp> (26 June 2005).

JETRO (2000). Japanese Firms in China Foresee Better Sales This Year. Japan External Trade Organization (JETRO), Japan. <http://www.jetro.go.jp/it/e/press/2000/may2.html> (22 November 2001).

Jiang, Y. (1999). *EIA in China with Particular Reference to Suzhou Industrial Park*. MSc Thesis. School of Biological Sciences. University of Manchester. Retrieved from EIA Centre Reference Database. <http://quercus.art.man.ac.uk/eia/dbsrch/search_details.cfm?search_Article_ ID=6923> (30 July 2002).

Lu, A.Y., and Wu, M.C. (1999). Economic value of climate prediction information – the case of Taiwan construction Industry. *Workshop on the Impacts of the 1997/99 ENSO (El Niño/Southern Oscillation)*. 1450–1510. <http://iri.columbia.edu/outreach/meeting/TWWS1999/> (22 November 2001).

MLIT (2001). *Construction Statistics Guidebook*. Ministry of Land, Infrastructure and Transport (MLIT), Japan. <http://www.mlit.go.jp/toukeijouhou/chojou/csg/csg_f.htm> (22 November 2001).

Ri, A. (1999, March 29). Environmental protection pipeline: A new transmit of construction waste on sites. *Construction Times*. <http://www.envir.online.sh.cn/info/np/file.asp?file=993-29-18.txt> (22 November 2001).

Saaty, T.L., and Vargas, L.G. (2001). *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*, International series in operations research and management science, Kluwer Academic, London.

Sawyer, T. (14 August 2000). Dot-coms need to court subcontractors. Document No.: MG20000823010000560. *Engineering News-Record*. 25(7), 35. <http://library.northernlight.com/MG20000823010000560.html?cb=7&dx=1005&sc= 0#doc> (15 January 2003).

SCH (2001). *Innovation in the Australian Building and Construction Industry, Year Ending December 2000*, Statistical Clearing House (SCH), Commonwealth Government of Australia. <http://www.sch.abs.gov.au> (22 November 2001).

SHAZAM (2000). *An Online Guide to SHAZAM: PART I – Learning the Basics: Statistics: Calculating a Geometric Mean*. <http://shazam.econ.ubc.ca/intro/gmean.htm> (26 June 2005).

Sina.com (2002). *China Quality Certification Center Put Family in Order*. <http://finance.sina.com.cn/b/ 20020719/234354.html> (23 July 2002).

Stenstadvold, M. (2000). The role of EIA in the planning and decision processes of large development projects in the Nordic countries: The case of the Gardermoen project. In Hilding-Rydevik, T. Editor, *EIA, Large Development Projects and Decision-making in the Nordic countries*, Nordregio Report 2001:6, ISBN 91-89332-18-0. 7-54. <http://www.nordregio.se/r0106.htm>, <http://www.nordregio.se/pdf/stenstadoh.pdf> (18 November 2004).

Tilford, K.R., Jaselskis, E.J., and Smith, G.R. (2000). Impact of environmental contamination on construction projects. *Journal of Construction Engineering and Management*, ASCE, 126(1), 45–51.

Transformation Strategies (1999). ISO 14000 mini-gap-analysis. <http://www.trst.com/gapanal.htm> (2 August 2002).

Tung, C.H. (1998). *Waste Reduction Framework Plan 1998–2007*, Government of Hong Kong SAR. Hong Kong.

Yang, S., Wen, T.Y., Wu, T.S., and Lee, Y.Y. (1989). *Research Method in Social and Behavioral Science* (13th edition), Tung-Hwa Book, Taiwan.

Author index

Subject index