Proceedings of the 2002 Winter Simulation Conference
E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

OPTIMIZATION OF THE WASTE MANAGEMENT FOR CONSTRUCTION PROJECTS USING SIMULATION

Mala Chandrakanthi
Patrick Hettiaratchi
Bolívar Prado

Engineering for the Environment Program
Department of Civil Engineering
University of Calgary
2500 University Drive NW
Calgary, AB, T2N 1N4, CANADA

Janaka Y. Ruwanpura

Project Management Specialization
Department of Civil Engineering
University of Calgary
2500 University Drive NW
Calgary, AB, T2N 1N4, CANADA

ABSTRACT

Growth in construction activities increases the amount of construction waste generated. Recycling of construction waste is an important component of environmentally responsible construction, as it reduces the amount of waste directed to landfills. In addition, it enhances the resource recovery for future construction work. A model is presented in this paper to predict waste generation rates, as well as to determine the economic advantages of recycling at construction sites. A future advanced version of the model can be applied to any construction site to: determine the amount of daily waste generation, resource and time requirement for sorting and transporting of recyclables. The model, therefore, is a valuable tool for construction managers interested in asserting the viability of recycling projects.

1 INTRODUCTION

Alberta Environment, in co-operation with a number of industry stakeholders, formed a Waste Reduction Advisory Committee to develop and implement strategies for reducing the amount of construction, renovation and demolition waste currently landfilled in Alberta. The University of Calgary's Center for Innovative Technology (CCIT) construction project was identified as a pilot project to demonstrate progressive and sustainable construction waste management practices. The project involves reuse and recycling of waste from a large and complex building construction site. The simulation template outlined in this paper is based on the work of Hajjar and AbouRizk (2000). Its purpose is to allow project managers to create an environmentally responsible construction project. By monitoring the construction operations of the CCIT project, the inputs for waste management model were collected to develop the preliminary version of the model. The addition of complex features stated in the latter part of the paper will benefit construction managers interested in applying this model to any construction facility to create an ideal scenario for waste management. This SPS model will enhance the decision making process and would allow optimized solution of the best scenario. The model takes into account the following factors, in order to optimize waste management: the sequencing of construction activities, type and the quantity of construction materials, percentage of waste generated through those materials, availability of resources, and capacity of collecting bins, costs and revenues.

2 CONSTRUCTION WASTE

A significant portion of municipality waste is construction related, so its reduction becomes important. Construction companies benefit by reducing the waste generation in a number of ways, including reducing transportation and landfill deposition costs, and the purchasing costs of virgin materials.

Waste production at a construction site may result from a lack of attention being paid to the size of the products used, lack of interest of contractors, and lack of knowledge about construction during design activities. About 1–10 percent by weight of the purchased construction materials, depending on the type of material, leaves the site as waste. Generally, 50 to 80 percent of the construction waste is reusable or recyclable (Bossink and Brouwers, 1996).

In terms of sustainability, the topic of management and reduction of construction waste can be considered an issue that focuses on the danger of depletion of materials used in the construction industry, such as timber, sand, and gravel. The topic also deals with the danger of environmental contamination because it is still common practice to transport construction waste to landfills. Construction and demolition waste as percentages of all solid waste that enter landfills in various countries are outlined in Table 1. The importance of the construction waste management is illustrated by the data. Identification of the composition of waste is also relevant for an efficient waste management process due to the amount of waste that is reusable or recyclable. Examinations of construction waste composition in Europe and the United States have yielded data summarized in Table 2 (Hettiaratchi et al., 1997).

3 EXISITING MODELS AND GUIDES FOR WASTE MANAGEMENT

Some researchers have developed tools and procedures to assist engineers and planners to identify and manage construction waste. The following are some of the significant contributions.

One of the tools available to help architects and engineers is a manual called WasteSpec. This manual includes specifications for construction waste reduction, reuse, and recycling. It also details specifications, information for bidders on estimating recyclable waste, worksheets and forms, and a list of further resources. The production of the manual was funded by the U.S. Environmental Protection Agency and WasteSpec, and was published in 1995 (http://www.tellus.org/sustcomm/ software, last accessed 13/05/2002). WasteSpec was used in twelve construction projects to provide information on the waste and cost impact of using specifications to reduce waste. In all but one of the projects, the cost of the project remained the same or was reduced compared to what it would have been otherwise. These projects represented the locations where landfill-tipping fees ranged from 17 to 110 US$ per ton. However, this manual cannot be used to identify daily waste generation which is important because it allows for optimal waste management based on uncertainties in daily work operations at site.

Table 1: Construction and Demolition Waste as Percentages of All Solid Waste that Entering Landfills (Bossink and Brouwers, 1996)

Country	Construction and Demolition Waste (by weight) percentage (%)
United States	26
Australia	20-30
The Netherlands	20-29
Germany	19
Finland	13-15

Table 2: Composition of Construction and Demolition Waste (Hettiaratchi et al., 1997)

Construction and Demolition (C&D) Waste Category	Composition (by weight) Percentage %			
	Spencer (1991)	Bossink and Brouwers (1996)	AEP (1995)	CH2M Hill (1992)
Asphalt	46%			
Concrete	14%	13%		70%
Metal	5%		7%	6%
Wood	26%		35%	13%
Clay Stone Tablets		29%		
Concrete and Wood Piles		17%		
Clay Bricks		14%		6%
Clay Roof Tiles		10%		
Cement Mortar		8%		
Paper/ Cardboard Packing Material		7%	8%	
Rubble, Aggregate and Ceramics including Concrete			24%	
Building Materials including Gypsum Board			17%	2%
Glass			3%	
Plastics			2%	
Other Mixed C&D Waste	9%	2%	4%	3%
TOTAL	100%	100%	100%	100%

WastePlan is a simulation model designed for integrated solid waste planning and analysis. It was developed in 1988 (http://peakstoprairies.org/topicchub/, last accessed 13/05/2002), and consists of four interactive modules. Those modules are waste definition, generation, diversion, as well as disposal and processing facilities. The information on waste type, categories, and waste streams should be given in the first module as inputs. This condition limits the application of WastePlan for construction waste management because of the stochastic nature of construction activities and their waste type and amounts.

4 OBJECTIVES OF THE SIMULATION MODEL

While the aforementioned tools are useful for specific projects, they do not incorporate construction schedule, an important factor in waste generation and management. Waste generation depends mostly on the performance of the construction operations and the schedule. Therefore, it is important to develop a simulation model that can incorporate the construction activity schedule in relation to the generation of waste. The model objective is to provide a tool to engineers, planners and constructors to determine the best scenario for a waste management plan for construction sites. The following are the sub-objectives of the simulation model.

- To estimate the amount of waste that one specific project will generate using its project plan (stochastic activity schedule),
- To quantify the reusable fraction of waste material,
- To optimize the methods to sort, store and to transport the collected reusable or recyclable materials,
- To identify the capacity, locations, and number of recycle bins required for a site.
- To identify costs for these operations and to optimize resource utilization in terms of labour and equipment for waste management.

A preliminary version of the simulation model was developed to achieve the aforementioned objectives using the special purpose simulation (SPS) developed by Hajjar and Abourizk (2000). A successful implementation of SPS models can be found in Ruwanpura et al. (2001) for construction operations. Computer simulation models are useful for studying complex systems that cannot be represented by equations or mathematical model. Generally, construction processes are complex, and are difficult to plan and control because they are affected by numerous uncertainties (Odeh, 1992). Making explicit what uncertainties exist, how large they are, and where they may manifest themselves is a first step towards designing a process.

5 SIMULATION MODEL FOR WASTE MANAGEMENT

This model was developed to simulate an integrated construction waste management system describing the areas of waste generation using any number of distinct sectors and waste types according to construction activities and the construction schedule. The modeling elements were selected to represent the on-site construction and recycling operations. The waste compositions, and common waste types were selected for each activity using observations made from site visits. Waste compositions depend mainly on activity, and the types of materials used. Five types of waste that are commonly identified in construction sites were considered in the model. Those waste categories are metal, wood, drywall, concrete and other waste. The structure of the model is depicted in Figure 1. A separate bin was used to collect each type of waste. The model was then developed to simulate the waste recycling activities. The model contains five representative modeling elements including a global modeling element similar to SPS developments by Ruwanpura at el. (2001). There are four child modeling elements under the parent element and named as the activity, sorting, transport, and cost. The inputs of the model can be given in individual elements or in the global element. Common resources required for several activities are given in the global modeling element. The current version of the SPS modeling elements, can be found in Figure 2.

5.1 Modeling Parameters and Processes

The global modeling element of the model has some input parameters, including available resources, volumes of each collection bins, and total project duration. It manages common resources such as waste collection bins, and labours in the waste management process.

The child element, "activity", generates daily waste from each activity according to the project schedule. Activity descriptions, starting time of each activity from the project start, and their durations are the primary inputs. The model will generate necessary daily outputs for the calculations at the sorting element.

The sorting element sorts the waste according to the material usage of each activity and the waste compositions. The main inputs of this element are total material usage for each activity, and waste compositions. When a collection bin is filled, a message is sent to the respective party to transport the waste into the final storage areas. The sorting of respective material cannot be carried out until the bin is returned to the sorting area.

The transport child element simulates the activities associated with transportation of sorted waste into the final collection points. The main input of this element is the transport time from the sorting area to the bins. Transporting the waste material off the site is not considered in the model.

The final child element, cost, is to calculate the cost of recycling, revenue from the recycling and the cost associated with landfilling. The main inputs are the landfilling unit cost for each material, and the revenue from each material. Hauling fees, disposal fees, and depending on the type of material recycled at site, the price paid for the recycler company in the local market are the main inputs.

5.2 Outputs

The main outputs of the model are: number of bins collected over time, revenue from the recycling activities, and cost of landfilling. Utilization of resources as statistics, and number of collected bins of each material when the project proceeds are calculated within the model. Amount of each material will be quantified thus allowing managers to better plan and reuse the said materials for other tasks that are yet to start. The time at which the final storage area is insufficient to store material will also be predicted.

Landfilling cost, one of the outputs of the model is very important because contractors could pay attention to activities that generate them. Generally, materials that cannot be recycled must be sent to the landfill by the contractor and they have to pay the landfilling fee, plus the costs of hauling. It is very important to enhance recycling activities at site, and to find the best alternatives for reusing materials in order to reduce operation costs for waste management instead of being paid high disposal fees. The disposal fee may be increased over time due to lack of enough space in most of the North American landfills. This will provide an opportunity for turning construction waste into an attractive business for the construction industry.

Sample analysis of some of the outputs is shown in Figure 3. In this analysis for one simulation run, the following are the summary of the results. The net savings includes the revenue generated from the recyclable materials and the savings from the same materials because they were not sent to the landfill.

Sites without recycling facilities:		
Landfilling cost	=	$ 6516
Sites without recycling facilities:		
Revenue from recycle	=	$ 2337
Landfilling cost for non-recyclable waste	=	$ 2276
Net savings	=	$ 6455

6 CONCLUSIONS AND RECOMMENDATIONS

The simulation model, developed with the use of Simphony special purpose simulation platform for waste man-

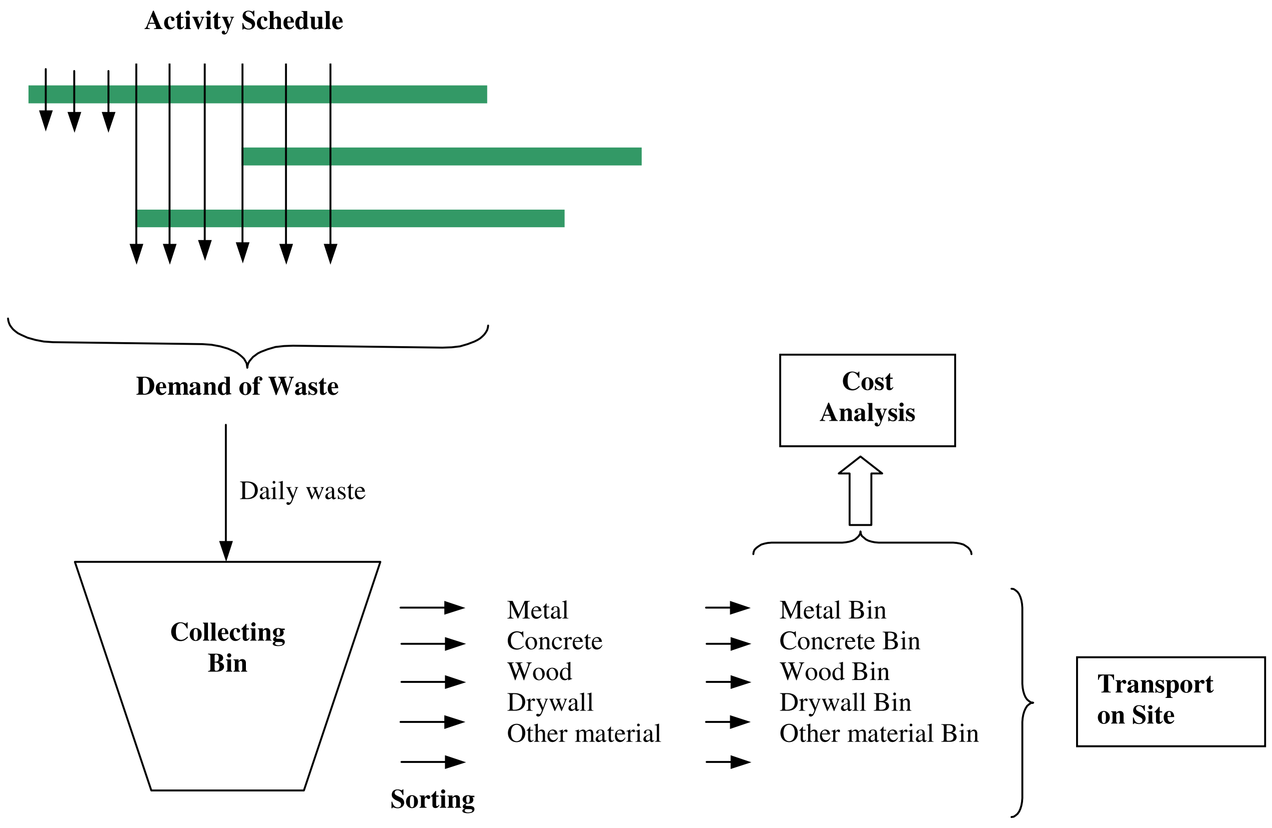

Figure 1: A Structure of the Model of the Waste Management Process

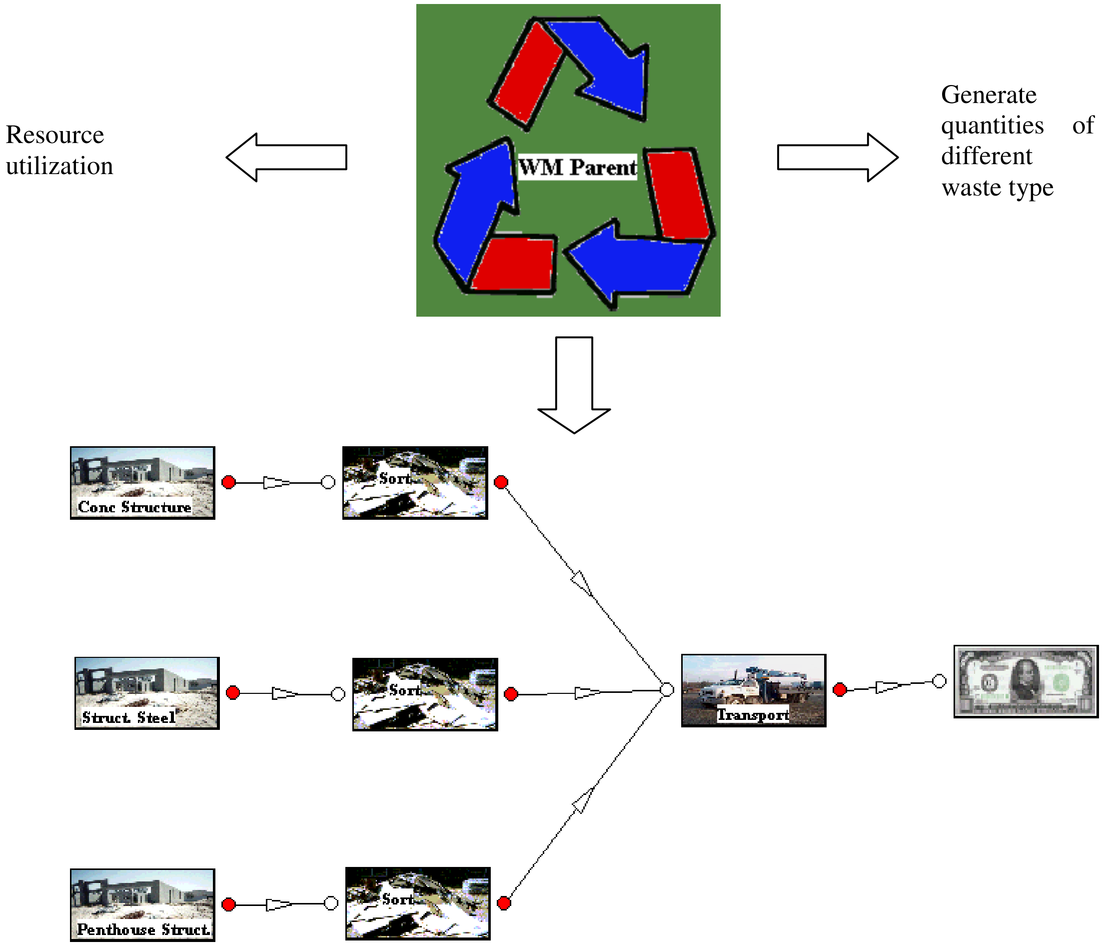

Figure 2: Layout of the Modeling Elements of the Simulation Model

Parameters | Outputs | Statistics

Output	Value
Revenue from Metal, ($)	773.333333333316
Revenue from Wood, ($)	560.222222222284
Revenue from Drywall, ($)	254.222222222217
Revenue from Concrete, ($)	750.000000000006
Revenue from Other material, ($)	0
Total Revenue, ($)	2337.77777777782
Cost of landfilling, ($)	6516.00000000028

Parameters | Outputs | Statistics

Output	Value
Number of metal bins collected	59
Number of Conctrete bins collected	50
Number of Other material bins collected	66
Number of wood bins collected	120
Number of dry wall bins collected	29

Figure 3: Outputs from Simulation

agement process is a new tool for construction industry. This model will be helpful for engineers, constructors and project planners to:

- develop a good understanding about the amount of waste generated due to construction scheduling
- design a waste plan for waste reduction, which will optimize the resources such as: crew, transportation equipment, number of bins at site, and capacity of the bins; and
- Make procedures that will cut down the costs such as hauling and final disposal at landfills.

The utility of the model becomes even more strategic when one considers the potential benefits of the consistent recycling of construction material waste. For example left over masonry materials can be crushed on site and used for fill as bedding. Drywall, copper pipes, conduit, electrical wires, and etc. can also reuse at site or resell to suppliers, constructors or public. Contractors, the environment, and the general public will reap the benefits of such practices.

Combination of the PERT template developed by Lu (2000) with the waste management model is recommended to provide more accurate estimations of waste generation due to the ability to model stochastic scheduling. Moreover, the collection of more information from construction sites will be able to improve the model and to develop a more comprehensive model in the future to predict and develop an efficient waste management plan.

REFERENCES

AEP. 1995. "Alberta Recycling Market Profiles: Construction and Demolition." *Alberta Environmental Protection*.

Bossink B.A.G, and H.J.H Brouwers. 1996. "Construction Waste: Quantification and Source Evaluation." *Journal of Construction Engineering and Management*, 122(1), 55-60.

CH2M Hill. 1992. Construction and Demolition Industry Waste Audit Study, Report submitted to Alberta Environmental Protection by CH2M Hill Engg. Ltd.

Hajjar, D. and S. AbouRizk. 2000. "Application Framework for Development of Simulation Tools." *Journal of Computing in Civil Engineering*, 14(3), 160-167.

Hettiaratchi, J.P.A., M.H. Ajward, R.C. Joshi, and To, M.1997. "Construction and Demolition Waste: Recycling Opportunities Assessment." In Proceeding of the International Conference on Engineering Materials, CSCE, Ottawa.

Lee, S. H., J.E. Diekmann, A.D. Songer, and H. Brown. .1999. Identifying Waste: Applications of Construction Process Analysis, proceedings IGLC-7, 63-72.

Lu, M. (2000). PERT Simulation Manual, Internal Report submitted to NSERC/ Alberta Construction Industry Research Chair in Construction Engineering and Management, University of Alberta.

Odeh, Abdalla. 1992. CIPROS: Knowledge Based Construction Integrated Project and Process Planning Simulation System, PhD dissertation, University of Michigan.

Residential construction-solid and hazardous waste, http://peakstoprairies.org/topicchub/, [last accessed 13/05/2002]

Reducing Vermont's construction waste stream, http://www.anr.state.vt.us/dec/wastediv/recycling/c&d.htm, [last accessed 13/05/2002]

Ruwanpura, J.Y., S.M. AbouRizk, K.C. Er and S. Fernando. (2001). "Special Purpose Simulation Templates for Tunnel Construction Operations." *Canadian Journal of Civil Engineering*, 28, 1-16.

Software: Solid Waste: WastePlan, http://www.tellus.org/sustcomm/software, [last accessed 13/05/2002]

Spencer, R. 1991. Taking Control of C&D Debris, *Biocycle*, 65-68.

AUTHOR BIOGRAPHIES

MALA CHANDRAKANTHI, is a graduate student in the Department of Civil Engineering at the University of Calgary. She earned her B.Sc Eng (First Class Honours) from the University of Moratuwa, Sri Lanka in 1999 and her M.Sc from the Asian Institute of Technology, Thailand in 2001. Currently she is working toward her PhD in environmental engineering. Her research topic is on the area of landfill gas migration.

JANAKA RUWANPURA, Ph.D., PQS, a Fulbright Scholar, is an Assistant Professor in the Project Management Specialization at the University of Calgary. He earned his B.Sc. (Honours) from the University of Moratuwa, Sri Lanka in 1992 and his M.S. in Construction Management from Arizona State University in 1997, and Ph.D. in Construction Engineering and Management from University of Alberta in 2001. He has obtained numerous scholarships and academic awards during his graduate studies. Special purpose simulation for tunnel construction operations was his doctoral thesis at University of Alberta. He developed a simulation tool that was successfully implemented in industry for project planning and bidding purposes. While pursuing his doctoral studies, he has published close to 20 papers in journals and conference proceedings covering a wide spectrum of research areas. Dr. Ruwanpura has experience working as a lecturer, professional quantity surveyor, project manager, and program developer for public and private sector firms in Asia and Canada.

PATRICK HETTIARACHCHI, Ph.D., P.Eng. is an Associate Professor in the Department of Civil Engineering at the University of Calgary. He earned his B.Sc. (Honours) from the University of Moratuwa, Sri Lanka and his M.Sc. from Asian Institute of Technology, Thailand, and M.Eng., Ph.D. in Environmental Engineering from University of Alberta. Dr. Hettiaratchi has extensive teaching, research and consulting experience in environmental engineering and science. His current research is in the areas of sustainable landfill technology, remediation of sites contaminated with complex hydrocarbons, greenhouse gas emission technology development, optimization of landfill construction and operation, and recycling of construction waste. Dr. Hettiaratchi is participating in several international collaborative research/education projects in Asia and South America. The Asian Regional Landfill study has partners from Thailand, China, India, Sri Lanka and Asian Institute of Technology (AIT, Bangkok). In 2001, he received the Iraj Zandi Award - presented by The Journal of Solid Waste Technology and Management "in recognition of his contribution to solid waste technology and management".

BOLIVAR PRADO is a Master in Science Student in the Department of Civil Engineering at the University of Calgary. He received his education from Ecuador and has obtained numerous scholarships in different countries as Sweden, Holland, and Canada. He worked for several years at the National Department of Construction of Public Schools in Ecuador in the area of Sanitary Engineering, and also worked as Advisor for International Cooperation for the Vice Presidency of the Republic of Ecuador. At present he is involved in a recycling project dealing with construction waste.