AFIT/GEE/ENV/93S-05

A PREDICTIVE MODEL FOR THE DETERMINATION OF THE ECONOMIC FEASIBILITY OF CONSTRUCTION AND DEMOLITION WASTE RECYCLING IN THE AIR FORCE

THESIS

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THESIS

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Byron L. Dixon

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Abstract

This study created a model to be used at a CONUS Air Force base to determine the economic feasibility of Construction and Demolition (C&D) waste recycling. Three areas were investigated to develop this model: the methods to determine amounts and types of C&D waste generated at a specific location, the markets for recycled C&D wastes, and the recycling methods currently available. From this data, gathered through records searches and interviews, a procedure was developed to perform cost/benefit analyses on the available recycling options. A model was then created based on these calculations which can arm a manager with information to either support or reject a recycling program by indicating cost savings or losses from recycling C&D waste. Also, the model aids managers in determining the approximate quantities of recyclable materials being generated, which could be valuable in reaching base recycling goals. To demonstrate the model, the feasibility of recycling C&D waste at Hill AFB, Utah in 1994 was evaluated. In addition to determining recycling feasibility, a method was presented to perform sensitivity analyses on the base-specific input variables. This procedure can help determine when it will become feasible to create a C&D waste recycling program.

A PREDICTIVE COST MODEL FOR THE DETERMINATION
OF THE ECONOMIC FEASIBILITY OF CONSTRUCTION AND DEMOLITION
WASTE RECYCLING IN THE AIR FORCE

I. Introduction

General Issue

In an effort to increase resource recovery programs within the Federal Government, President Bush issued Executive Order 12780 on 31 October 1991. This order specifically calls for Federal Agencies to "promote cost effective waste reduction and recycling of reusable material from waste generated by the Federal Government" (11:1). In response to this order, the Assistant Secretary of the Navy (Installations and Environment) asked the Society of American Military Engineers' (SAME) Environmental Affairs Subcommittee to recommend pollution prevention initiatives that relate to Department of Defense (DOD) design and construction programs. Although results from this study have not yet been formalized, the draft report includes the following recommendation:

> [DOD should] establish policy consistent with safety, environmental, and health requirements, requiring waste associated with demolition, site clearance, and construction (including renovation and

> repair) be segregated and entered into reutilization or recycling processes to the extent feasible. (29:4)

This recommendation is in line with the current Air Force Pollution Prevention Policy Directive which specifically states that the Air Force will reduce municipal solid waste through source reduction and recycling (15:1). As a follow on to this policy directive, a Pollution Prevention Program Action Plan has also been issued which sets the goal to reduce municipal solid waste by 50% by 1997. However, considering the continued decline of the DOD infrastructure budget, the recommendation to recycle construction and demolition (C&D) waste should only be implemented if proven to be economically feasible.

Specific Problem

The economic feasibility of C&D waste recycling should be determined at base-level, since the disposal costs, recycling costs, and recycling markets vary across the Continental United States (CONUS). Even at the base-level, a number of predictions and assumptions are required to thoroughly assess the influencing conditions which effect the feasibility of C&D waste recycling. The Air Force managers assigned to this duty must first forecast the amount of C&D waste that will be generated at the base. They must also identify the C&D recycling industries and markets available in their local area. This data must be used to compare the cost of landfilling the waste to recycling it.

A predictive model can be developed to aid the base-level manager in the decision of whether to implement a C&D recycling program, based on economics.

However, to ensure accurate analyses, the model must be capable of generalizing the influencing conditions unique to each base. The three most important of these conditions are the varying amounts and types of C&D waste, local landfill costs, and differing recycling markets.

Since bases have varying amounts of annual construction/demolition projects, a generalized model is needed which could reasonably predict the quantity and composition of a particular base's C&D wasteflow. This information will be crucial to the determination of costs and available markets.

Currently, the location and number of C&D recycling companies in the United States are limited. Traditionally, the catalyst of growth for the C&D recycling industry has been high landfill costs. Since landfill costs are a primary function of available space and local regulations, they vary significantly across the CONUS. Consequently, the locations of the C&D recycling companies directly correlate to the areas of the country where landfill fees have increased dramatically in the last five years (49:28, 37:68, 32:36). A model to determine economical feasibility of recycling C&D waste should, therefore, be flexible enough to account for varying landfill costs.

To determine the economic feasibility of C&D waste recycling in an area, the available markets for the recycled materials must be identified. In many cases, these markets are dependant on a number of issues, including the availability of local natural resources and the types of industry in the area (6:33, 2:61). To account for these differing conditions, the model should be structured to accept various market scenarios.

Research Objective

The purpose of this research is to create a generalized predictive model which will help Air Force managers determine the economic feasibility of C&D waste recycling.

Investigative Questions

To meet the stated research objective, the following investigative questions must be answered:

1. What are the total annual quantities and types of C&D wastes generated at individual Air Force bases?

2. What markets are available for these recycled C&D wastes?

3. Based on the markets for the generated C&D waste materials, what are the costs and benefits associated with recycling C&D waste?

Scope and Limitations of Study

In addition to economic feasibility, several other issues could be addressed to fully evaluate the extent to which C&D waste recycling is feasible. Some of these issues include the possible environmental impacts of the recycling process, possible Air Force liability, and the regard for worker and public health. Although all of these issues may be important and could be considered, they will not be addressed in this study. This study will be restricted to providing a predictive cost model for Air

Force CONUS bases only. The model may, however, have applications which can be adjusted to be of use at other DOD CONUS installations.

Definition of Key Terms

Several key terms will be used throughout this study and must be defined to fully understand the work that follows.

Construction and demolition (C&D) waste: "all waste resulting from the construction, renovation, and demolition of buildings, roads, docks, piers, and all other structures" (37:65).

Economic feasibility: the practicality with regard to cost versus benefit of recycling vice landfill disposal of C&D waste (49:14).

Estimating factors: Unit measurements of construction, demolition, or renovation of facilities used to estimate the generation and composition of C&D waste at a particular location (10:4).

Horizontal construction/demolition: construction or demolition of roads, airfields, bridges, landscapes, docks, and other non-building appurtenances (9:6).

Recycling: the use of an existing material to generate a new, usable product (5:78).

Unit measurements: basic and accepted units of measure used in the construction industry (e.g. square foot, linear foot, etc) (30:12).

Vertical construction/demolition: construction, renovation, or demolition of buildings (9:6).

Overview of Chapters

In this chapter, the need to determine the feasibility of C&D waste recycling is discussed. Specifically, the creation of a generalized, predictive model which can be used to help base-level Air Force managers determine the economic feasibility of C&D waste recycling, given base-specific criteria, was proposed.

In chapter II a review of the literature on C&D waste recycling is addressed by discussing past C&D wasteflow studies, existing recycling technologies and markets, and current recycling companies. The literature review also discusses national pollution prevention trends which led to the passage of Executive Order 12780.

Chapter III addresses the methodology used to create the economic feasibility model. The chapter begins with a presentation of the technique employed to estimate the types and quantities of C&D waste generated at a specific base. A review of the literature concerning the creation of the predictive models is also included in this chapter. Finally, chapter III addresses the method of gathering the data needed to compute costs and benefits of C&D waste recycling.

The economic model used to determine the feasibility of C&D waste recycling is presented in Chapter IV. The assumptions and constraints used in the development of the models are discussed in this chapter, as well.

Lastly, Chapter V includes a discussion of recommendations for using the model and some suggestions for future research on this topic.

II. Literature Review

Introduction

The construction and demolition industry has been termed "The last major industrial sector to undertake significant waste reduction and recycling programs" (27:35). Although some efforts to recycle construction and demolition (C&D) waste are now being made, the market is certainly still in its infancy. With recent national emphasis placed on pollution prevention, and the large amount of construction and demolition generated by the Air Force, there is great potential for Air Force involvement in C&D recycling programs. The purpose of this chapter is to present a review of the literature related to the technologies, incentives, and problems in the C&D waste recycling market, and to discuss the role economics must play in determining the feasibility of recycling C&D waste in the Air Force.

Data for this review was drawn from a search of published literature on C&D waste, recycling of solid waste, studies of solid waste landfills, and applicable governmental laws. Using this data, the chapter begins with a review of national legislation and policy that led to the consideration of C&D waste recycling in the Air Force. This will be followed by an analysis of available C&D wasteflow composition studies. The recycling of these wastes will then be discussed. Finally, the chapter will conclude with a discussion of the relevance of this review to the research question noted in Chapter I.

Recycling Air Force C&D Waste

The Pollution Prevention Act of 1990, which was passed as part of the Omnibus Budget Reconciliation Act of 1991, declared pollution prevention to be a national policy (12:57). The Environmental Protection Agency (EPA), the agency charged with the enforcement of the Pollution Prevention Act, defines pollution prevention as follows:

> Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous and nonhazardous materials, energy, water, or other resources as well as those that protect natural resources through conservation or more efficient use. (40:1)

To stress the importance of the Federal Government's compliance with the Pollution Prevention Act, President George Bush issued Executive Order 12780 on 31 October 1991. This order specifically calls for Federal agencies to "promote cost effective waste reduction and recycling of reusable material from waste generated by the Federal Government" (11:1) Several Department of Defense (DOD) initiatives were implemented in response to this order, of which two were of particular importance to this study.

First, the Assistant Secretary of the Navy (Installations and Environment) asked the Society of American Military Engineers' (SAME) Environmental Affairs Subcommittee to recommend pollution prevention programs that relate to DOD design and construction efforts. In their draft report, the SAME subcommittee recommended that DOD establish policies requiring C&D wastes be recycled to the extent feasible

(30:4). The second DOD initiative implemented as a result of Executive Order 12780 was Air Force Policy Directive 19-4, issued by order of the Secretary of the Air Force. This policy directive, entitled *Pollution Prevention*, contains a section which explicitly states:

> The Air Force will reduce municipal solid waste through source reduction and recycling. Installations will participate in recycling and composting programs conforming with regional solid waste management plans. (15:1)

Since the Air Force's pollution prevention policy is in agreement with SAME's recommendation that DOD recycle C&D waste where feasible, it can be assumed that Air Force managers will soon be required to evaluate the feasibility of recycling their C&D waste.

C&D Waste Composition

Several studies have concluded that construction and demolition waste accounts for between 10 and 20 percent of solid waste generated in the U.S. (48:12, 27:35, 36:43). However, the characteristics of this major landfill contributor has not yet been determined nationally. A number of reports were found during this review which attempted to quantify the composition of specific C&D wastestreams.

The estimation of vertical demolition waste generation nationally was first attempted in 1973 by Jones, et al. The research methodology for this study was based on the important assumption that the materials used in the construction of a facility would appear as a waste source at the end of that facilities lifespan. Since the authors estimated the average lifespan of a facility to be 40 years, they gathered data on the construction materials input for specific areas in the 1930s. Although many of the authors' assumptions were later proven to be incorrect, they laid the groundwork for future studies in this area (26:1-3).

In 1976, an investigation of the potential for resource recovery from demolition waste was conducted at the Massachusetts Institute of Technology (MIT) by Wiesman, et al. In this study, data was obtained by taking samples of vertical demolition activity in three cities: Los Angeles, Boston, and Atlanta. The study's population consisted of buildings razed from 1960-1975. The authors then applied some of the assumptions made in the Jones, et al. study to conclude that the amounts and types of waste material generated during the demolition of the facilities was approximately equal to the amounts and types of materials that were initially used during their construction. From these results, Wiesman, et al. calculated an estimate of the total C&D waste quantity and composition for the United States (49:8-15).

In 1979, the NSF sponsored a new demolition waste study aimed at extending the 1976 work to the point where the government would have a valid data base upon which to establish policy for demolition. This report extended the data collection from the 1976 study and developed a predictive model for demolition-waste generation in any year and in any particular region of the country (48:7).

Although several national studies of C&D waste composition were conducted in the 1970s, the only efforts in this area during the past 13 years have been conducted locally, for specific economic reasons. One such study was accomplished for Berkshire County, Massachusetts by Hayden-Wegman. Another similar study was performed for the State of Vermont by C.T. Donovan and Associates (36:43, 48:1). The third analysis was conducted by Innovative Waste Management for the Metropolitan Council of the Twin Cities Area, Minneapolis, Minnesota (29:1).

The Massachusetts study was accomplished by interviewing homebuilders, landscapers, waste haulers, woodworkers, and local governments in a rural county (36:42). The methodology used in the Vermont study involved interviewing major C&D waste generators from across the entire state (48:3). The study in Minnesota was conducted by surveying several construction waste generators in the Twin Cities area (29:3). The results from the various studies indicate that the determination of quantities of the various C&D wastestreams is dependant upon the location and methodology used in the studies. However, it should be noted that the wastestreams considered were all chiefly composed of only three items: asphalt, concrete, and wood (36:43, 48:12, 29:4-5).

C&D Waste Recycling

Although the idea of recycling C&D waste has been around for over 20 years, only a small amount of this wastestream has received any attention from recyclers until the last few years (23). To better understand this topic, a review of past efforts to evaluate the economic feasibility of demolition waste recycling is presented. This is followed by a discussion of present recycling technology, current recycling companies, and incentives for future growth of this market. Finally, some problems C&D recyclers are facing is addressed.

Economic Feasibility Studies. Two previously mentioned studies were found which addressed the economic feasibility of recycling C&D waste. Both studies, as noted above, were sponsored by the NSF. The first study, conducted in 1976, concluded that recycling C&D wastes at that time may have been feasible in the larger cities, where landfill space was already becoming scarce (49:15). The second study, conducted in 1979 as a follow-on to the previous work, also limited the possible economic feasibility of C&D waste recycling to the largest cities (48:224). In both studies, the low cost of landfill disposal in most areas of the country was a key cause of the infeasibility of C&D waste recycling (49:15, 48:228).

Technology. Recycling markets are currently emerging for most of the materials in the C&D wastestream. From the previous studies mentioned above, these materials can be divided into the categories of asphalt, concrete, wood, gypsum wallboard, and others (36:43, 48:12, 29:4-5, 49:15, 48:25).

Asphalt. Asphalt recycling is traditionally accomplished by first taking asphalt removed during demolition back to the processing plant. There, it is melted and screened. Next, the aggregate is removed, and it is remixed with new bituminous and sent to a new construction site (38:53).

Concrete. Like asphalt, concrete recycling generally involves removing the waste from the demolition site, reprocessing the debris, and then shipping it back to a new construction site. The largest use for recycled concrete to date is as processed concrete stone, which closely resembles natural crushed stone. In this form, it is quite suitable for use as base course beneath roads (2:60, 13:31, 28:77).

Large pieces of broken concrete can be used as riprap. Riprap is a material used to stabilize steep slopes and shorelines in many areas of the country (35, 2:60).

Wood. The fastest growing recycling market within the C&D industry involves the reuse of wood (21:77). In fact, a 1991 study on the need to ban wood from landfills in Illinois concluded that the ban was unnecessary since wood recycling was becoming a predominant trend among contractors (24:8). Currently, wood is recycled for several uses. The majority of recycled wood is processed into chips and used either to fuel wood-fired boilers or to create manufactured building products, such as particle board. Another use for recycled wood is as an admixture for mulch. In addition, the use of wood as a bulking agent for sludge compost has also shown promising results (21:77, 17:87, 31:74, 33:85).

Gypsum Wallboard. In many areas, gypsum wallboard makes up 15 to 20 percent of the C&D wastestream. New West Gypsum, a Canadian firm, has developed a method to turn this waste into new wallboard by mixing recycled gypsum with virgin ore. The backing paper from the scrap wallboard is also reprocessed and made into new sheets to be used on the recycled wallboard (32:35). Another Canadian company, Canagro Agricultural Ltd., has created a market for recycled gypsum wallboard that has grown to the point it can no longer meet the demand. The company mixes some of the recycled gypsum with raw gypsum, and sells the product as fertilizer. The remainder of the waste gypsum is processed, packaged, and sold as a very popular cat litter. Finally, the flakes of paper backing and gypsum residue not removed in processing are sold to farmers as a bedding for livestock (27:36).

__Other Materials__. Many of the materials that make up the remainder of the wastestream also have recycled uses. Table 1 lists these wastes and their uses (37:66).

TABLE 1
END-USE MARKETS FOR OTHER C&D WASTE (15:66)

Waste Type	End-Use
Metal	"The gold of C&D recycling"
Aluminum	Remelted
Copper	Remelted
Other	Scrap metal dealers
Brick	Masonry, landscaping
Glass	Fiberglass insulation
Plastic	Insulation
Topsoil	Landscaping, landfill cover
Cardboard	New cardboard, fuel pellets
Fixtures, doors, etc	New construction

__Recycling Companies.__ Although recycling markets are developing for most C&D debris, relatively few recycling companies are presently in operation. Most of the existing companies found in this review operate in the Northeast, California, and Florida. The location of these

businesses directly correlates to areas in which the cost to landfill C&D waste has increased dramatically in the last five years (49:28, 37:68, 32:36, 21:76, 38:53).

The study of C&D waste conducted for the State of Vermont found that, of the 35 C&D recycling businesses in the state, only 2 process the full C&D wastestream. The other facilities handle only asphalt,

concrete, and/or wood (48:65-66). The San Francisco Bay area, on the other hand, claims the most organized of the sparse C&D recycling industries. Several recycling businesses are flourishing there because municipalities are beginning to target industrial waste to meet state-mandated recycling goals. As in the Northeast, the majority of the waste targeted for recycling is limited to asphalt, concrete, and wood (23). Similarly, Kimmins Recycling Corporation has established a network of recycling centers across urban areas of the state of Florida, except each facility accepts almost all C&D waste (49:26). In addition, Realco Recycling Company of Florida has established a recycling-hauling operation which recycles 99.7 percent by weight of all C&D waste that it receives (34:46, 35).

Incentives. Although few C&D recycling companies presently exist in the United States, several important incentives are developing which could soon make C&D waste recycling one of the fastest growing industries in the nation (23). These incentives can be grouped into the following areas: laws, cost, and governmental assistance.

Laws. Traditionally, the federal government has paid little attention to solid waste in general, and no attention to C&D waste in particular. According to Ellen Pratt of the EPA, "C&D waste is not getting a lot of attention from the EPA because the agency needs more information about C&D recycling." In 1990, the

EPA published a report entitled *Characterization of Municipal Solid Waste: 1990 update*. According to Robert Brickner and Eileen Glass, authors of the article *Shedding Light on C&D Issues*, the report did not even mention C&D waste (5:70).

In the past, state governments regulated C&D waste disposal using the assumption that C&D debris was inert and harmless. Because of this assumption and the fact that C&D waste items were bulky and hard to compact, most states provided separate landfills for C&D debris. These landfills fell under different regulations than those for ordinary Municipal Solid Waste (MSW). Requirements for leachate collection systems and liners for C&D landfills were far less strict, and even nonexistent in some states. Unfortunately, some recent studies have indicated that landfilled C&D waste may not be as harmless as originally thought.

One of the studies was accomplished by Sanifill Inc., as reported in *Waste Age* in 1991. This study, reported that groundwater around the three C&D waste landfills in Houston, Texas was adversely affected by leachate. Another study, as reported by *BioCycle*, was commissioned by the Greater Vancouver Regional District. This effort concluded that C&D waste landfills in British Columbia were producing noxious Hydrogen Sulfide gas and metallic Sulfide leachate.

Although no conclusive evidence has been presented which confirms that C&D waste poses a significant environmental threat, many states have begun to toughen their C&D landfill regulations to resemble other MSW landfill requirements (7:15, 49:27, 36:42).

Cost. When the one of the first studies was conducted on C&D waste in 1976, the national average cost for landfilling this debris was reported to be $4.90 per ton (49:13). This cost has soared to a 1992 average of $32.00 per ton (2:58). Even considering inflation over the past 16 years, the real price increase is still over 300 percent (18:1). This drastic increase in largely due to changes in the previously mentioned laws (7:14).

In addition to the dumping fees, the cost to transport the waste is an important consideration. Transporting debris to a landfill, which is usually located far away from the urban areas where most construction jobs are located, can be very expensive. However, recycling facilities can be located in a city, much closer to the jobs. This saves considerably on transportation costs (41:138). A review of reports from existing C&D recycling companies show their tipping fees range from $1.00 to over $100.00 less than the landfill charges in their local area (36:43, 32:36). These cost considerations alone will eventually create a solid C&D recycling market nationwide.

Governmental Assistance. Although governmental assistance alone will not create a successful C&D recycling market, it could help to expedite one. The Federal Government committed to aiding recycling business in the Pollution Prevention Act of 1990. This measure authorized the EPA to provide matching funds to states who establish technical assistance programs for recycling companies (12:54).

Some states, in turn, are working to implement these assistance programs. Vermont, for instance, hired a consulting firm to create the wasteflow study previously mentioned in this review. In addition to characterizing the wastestream, the report also outlined steps to create a successful recycling business. Vermont is now in the process of establishing a state-funded revolving loan or interest subsidy to facilitate investment into recycling markets (37:67-68). Similarly, the State of Washington is working through their Department of Economic Affairs to encourage recycling by requiring state-funded construction projects to include recycled products when possible, and assisting local recycling companies to improve their processes (3213:36). Other states actively involved in developing aggressive C&D recycling programs include Florida, Minnesota, Texas, and California.

Problems. As with any large process change, there are obstacles to overcome in the C&D waste recycling industry. One problem is the segmented nature of the construction business, and the large number of small companies. Another difficulty is the lack of space for sorting and storing recyclables on a construction job. Most construction debris bins are accessible to the public, and can easily be contaminated by unauthorized dumping (11:35). Yet another concern involves attaining permits to operate C&D recycling facilities. Many recycling business owners have stated that it is very frustrating to try to obtain local approval for a C&D recycling facility. Since currently there are very few recycling facilities, waste from large distances away are brought in to those who are in operation. Many residents around these facilities quickly develop a *not-in-my-backyard* attitude about this practice (2:75-76, 20:61). In addition, many local environmental regulators have shown concern regarding possible environmental contamination caused by the various recycling operations (35, 19:58).

The most significant barrier, however, is the lack of nationally established recycling markets for C&D debris. To encourage further development of these markets, more reliable information on C&D debris is needed (11:35).

Conclusion

There are many advantages to recycling C&D waste. Some of these include reducing landfill use 10 to 20 percent, meeting recycling goals, saving natural resources, and possibly reducing liability should C&D waste be deemed environmentally hazardous in the future. Although these are all noble reasons to create a C&D waste recycling program, the key advantage that will make a difference to the construction industry, as well as the Air Force, is cost savings.

In the 1970s, experts found that C&D waste recycling was not economically feasible due to the abundance of inexpensive landfills around the country. This resource is rapidly becoming depleted, even in the most rural locations. The rising cost of landfill disposal, along with the other incentives mentioned above may be the required catalyst to make recycling a feasible option for handling C&D debris.

III. Methodology

Introduction

This chapter describes the research methodology needed to construct a predictive model which will evaluate the economic feasibility of construction and demolition (C&D) waste recycling at Air Force installations. The construction of this model will require data which answers the following investigative questions:

1. What are the total annual quantities and types of C&D wastes generated at individual Air Force bases?

2. What markets are available for these recycled C&D wastes?

3. Based on the markets for the generated C&D waste materials, what are the costs and benefits associated with recycling C&D waste?

This chapter addresses the techniques which were employed to gather the data needed to answer each of these questions sequentially. The chapter concludes with the presentation of a proposed model which utilizes all of the gathered data to determine the economic feasibility of C&D waste recycling at a particular base.

C&D Waste Generation

To answer the first investigative question, the quantities and types of C&D waste generated at a base during a specific period must be estimated. In addition to the research efforts mentioned in Chapter II, some similar efforts important to the methodology of this research have been made to characterize demolition wastes generated on a national and regional level. Therefore, a brief review of these past works is offered. This review will be followed by a presentation of the methodology which can be used to estimate C&D waste at a particular Air Force base.

Wilson, et al. Study. In 1979, the authors of the 1976 MIT study mentioned in Chapter II performed another demolition waste study. This study was aimed at extending the 1976 work to the point where the government would have a valid data base upon which to establish policy for demolition, if needed. The authors of this report extended the data collection from their 1976 study from three major cities to a total of 27 cities, small towns, and counties. In the 1979 study, they also offered some correlation analyses between demolition waste generation and several possible influencing factors. These factors included various census data from the sample areas, such as percentage of vacant housing units, percentage of owner-occupied housing units, average rent values, and population density. While some positive correlations were discovered in the study, the authors also found that in many cases over 50 percent of the demolition waste generated failed to correlate to any of the census data analyzed (48:7-15).

US Army Corps of Engineers Studies. Two studies, conducted in 1976, were commissioned by the U.S. Army Corps of Engineers' Construction Engineering Research Laboratories (CERL) at Battelle Columbus Laboratories. These studies were aimed at documenting demolition techniques used, costs incurred, and wastes produced in normal Army peacetime activities. Both of these works noted that Army structures tended to be predominantly composed of either wood, or brick/concrete. These results were more restrictive than the spectrum of structures encountered by either of the Wilson et al. works (9:56, 10:87). The first Army study, dated October 1976, provided a means of estimating volumes of vertical demolition waste based on the type of structure and its area (10:71). The second study, dated December 1976, provided estimates of the composition of the C&D wastestream for vertical demolition on a typical Army installation (9:11).

C&D Waste Quantities Generated at an Air Force Base. Considering the available information pertaining to calculating C&D wasteflows as provided by the studies previously mentioned in this chapter and Chapter II, a records review of these reports was used to determine a method of estimating waste quantities generated at a particular Air Force base. Each of the studies noted, however, presented disparate methods of calculating waste quantities. Therefore, reasonable judgement was used to select the results from the study which most closely represents the cases typical to an Air Force installation. From this evaluation, the US Army studies were selected over the other studies mentioned primarily for two specific reasons. First, the sample population for the study included several military installations, including an Air Force base. Second, the Army's studies demonstrated a more valid relationship between their explanatory variables (the type and area of the demolished structures) and their dependant variables (amount of waste generated). The other studies provided estimators for the amounts of waste generated depending on various census data, such as the size of the sample population. Since the residential area of an Air Force base is much less populated than that of a city of equal size, these factors may not be applicable to a base.

Markets for C&D Recycled Materials

To answer the second investigative question, data was gathered to help identify and characterize the available markets for the C&D waste-recycled products. This data was obtained through an extensive literature review as well as through personal interviews with C&D waste recyclers and state and local solid waste managers. Through this process, several important characteristics of each of the recycled materials in the C&D wasteflow was evaluated.

Cost-Benefit Analysis

To determine the economic feasibility of C&D waste recycling, the costs and the benefits of the proposed program were analyzed. The method chosen to accomplish this has been specified in a class handout, entitled *Pollution Prevention Economics*. James Aldrich, PhD, author of the handout, states that the first step in determining the cost of a project is to establish a baseline for the analysis (1:73). For the purposes of this study, the baseline was considered to be the status-quo alternative, which is the disposal of all C&D waste in landfills. The method of computing the baseline cost was determined by performing a material balance where all relevant input expenses and output revenues for the process are identified. A conceptual depiction of the baseline material balance is presented in Figure 1.

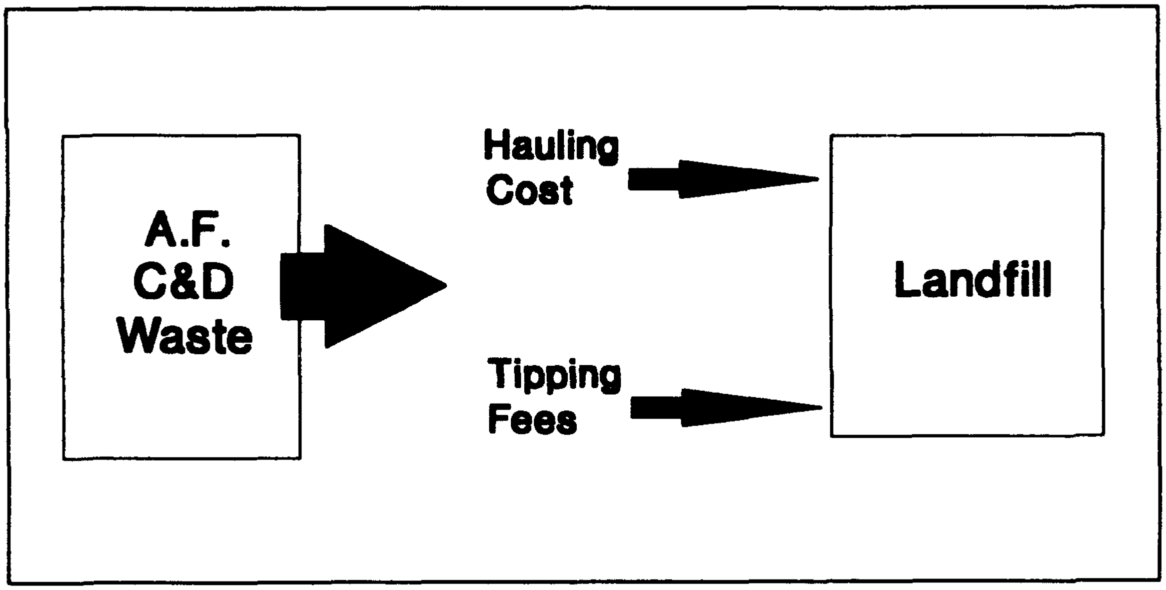


Figure 1. Baseline Material Balance (43:15, 17:14)

Once a material balance for the baseline option has been created the cost of recycling must be approximated. The first situation addressed is the case where the Air Force base is located near a full-scale C&D recycling center. Figure 2 shows one conceptual material balance for this case.

For the case where little or no recycling capability is currently available to a base, a more detailed analysis of recycling cost was required to determine the feasibility of contract recycling options. To accomplish this analysis, an estimation of the cost of constructing and operating a recycling plant was required. This information was compiled through records searches and interviews with C&D waste recyclers. The material balance for this case is shown in Figure 3.

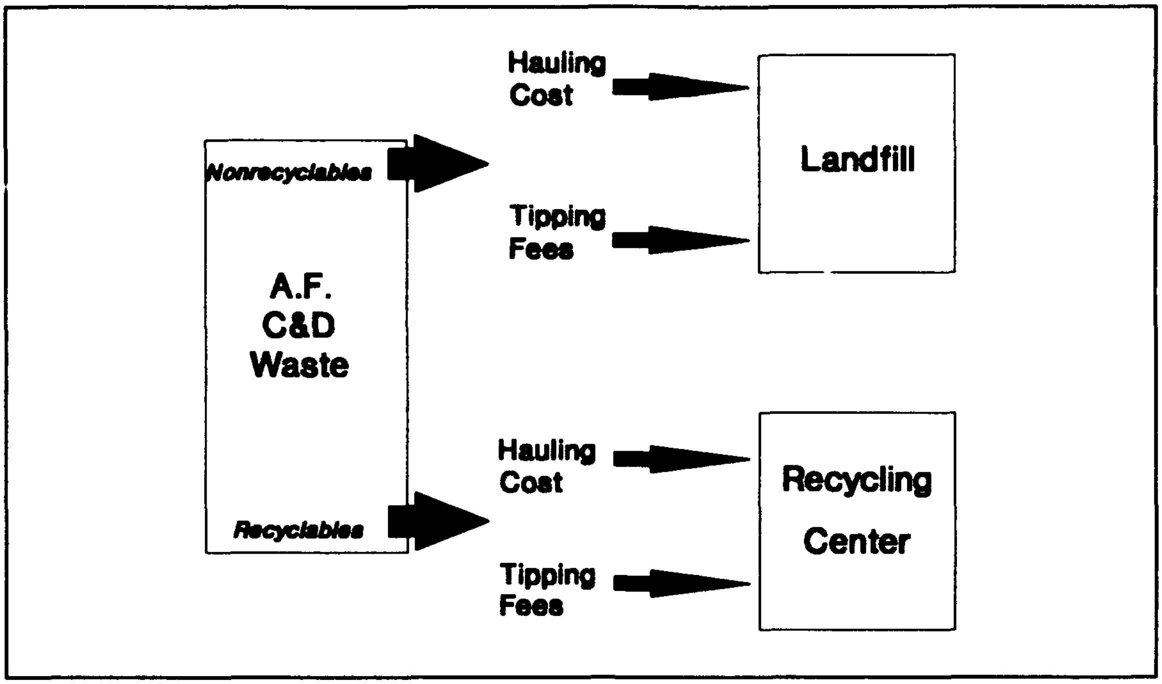


Figure 2. Material Balance for Bases Near C&D Recycling Facilities
(8:26, 29:10-11)

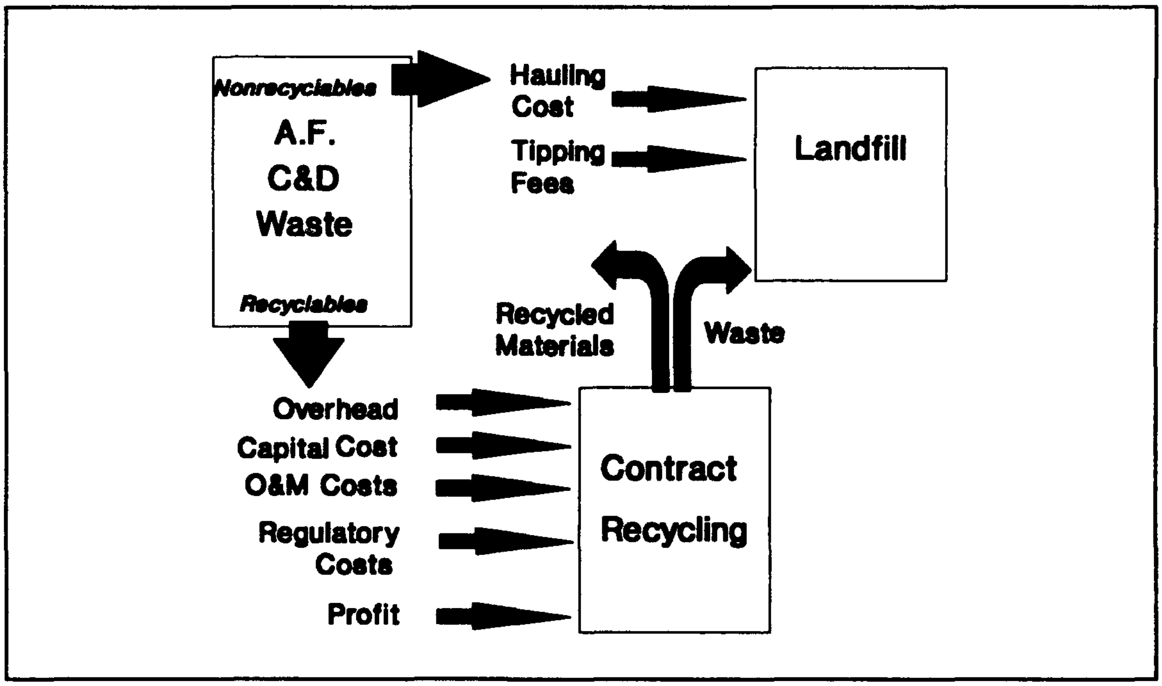


Figure 3. Material Balance for Base Without C&D Recycling Center
(35, 8:26)

An Economic Model

Once all of the answers to the investigative questions were accumulated, a model was developed which provides an indication of if and when it is economically feasible to recycle C&D waste for a specific base. In order to furnish a demonstration of this model, a sample base was evaluated for a specific time period. Hill AFB, Utah was selected for this evaluation, and the timeframe for evaluation was selected to be the year 1994. The selection of Hill AFB for this evaluation in no way represents a valid or reliable statistical sample. Instead, the data from Hill was used merely to describe the method by which any Air Force manager tasked with a similar responsibility can approximate the feasibility of C&D recycling at a specific location.

The methodology used to conduct this evaluation will be presented by first discussing the data needs and collection techniques. This will be followed by a discussion of the methods used to determine the economic feasibility, considering the data collected for Hill AFB. Finally, the procedure used to analyze the variance of each of the parameters and to predict the economic feasibility, given a change in some of the given parameters will be offered.

Data Requirements and Collection Methods. The data required to operate the model was determined through a review of the previously mentioned cost/benefit analyses. To determine the C&D recycling options disposal requirements in the vicinity of Hill AFB, a questionnaire was sent to the Hill Simplified Acquisition of Base Engineering Requirements (SABER) contractor, BENECO Enterprises. BENECO has been the SABER contractor at Hill for seven years, and Mr. Russell

Jex, the BENECO program manager contacted, has been in charge of these operations for five years. During that time, BENECO has been responsible for over 360 projects at Hill that range from large vertical construction to small remodeling jobs (25). Therefore, Mr. Jex was considered to be an expert on the construction waste disposal markets and conditions in the area. Appendix D (a) lists the questions sent and responses obtained from Mr. Jex.

In addition to the market and disposal conditions, the amount of C&D waste produced at Hill AFB needed to be estimated for a given year. To gather this information, a Civil Engineering programmer, Mr. Ron Daniels, was solicited for support through a telephone interview. The year 1994 was selected as the timeframe for evaluation since the estimates of construction and demolition activity for this year were considered by Mr. Daniels to be fairly accurate. Appendix D (b) lists the questions asked and responses given from Mr. Daniels.

Determining Economic Feasibility. The economic feasibility of C&D waste recycling was determined for Hill AFB by first developing formulas to calculate the overall costs and benefits of the applicable baseline and recycling options. These formulas were then included into a computer spreadsheet model. The site-specific data that was gathered from Hill was loaded into the spreadsheet model as the *input variables*. Given these variables, a *feasibility factor* was determined for 1994 at Hill AFB. This factor is defined as the cost of the most economic baseline alternative minus the cost of the most economic recycling option. Therefore, if the feasibility factor were determined to be a non-negative number, C&D waste recycling could be considered feasible.

Sensitivity Analysis and Future Economic Feasibility. A sensitivity analysis for each of the input variables was conducted by changing their values in the spreadsheet model from -100% to 200% of the given amount, while holding all other input variables constant. In some cases, the allowed variance was less due to practical reasons. For instance, the percentage of concrete-type vertical demolition was not allowed to vary above an 80% addition to its estimated amount of 20%, since any variance above that amount would exceed 100% of the total amount of demolition.

Using the model, new feasibility factors were determined for each variance of the input variables. The relationships between the feasibility factor values and the independent variances of each of the input variables were then plotted. From these graphs, the parameters whose variance caused a pronounced change in the feasibility factor were identified as *indicator variables*. The values of the indicator variables were then allowed to vary simultaneously, and the effects on the value of the feasibility factor were again plotted.

Summary

This chapter provided a description of the proposed methodology needed to create a predictive model to determine the economic feasibility of C&D waste recycling at any given Air Force base. First, methods were proposed to gather the data required to answer the investigative questions. This included a review of past methodologies used in similar studies and a discussion of how the past research will influence this study. The chapter also identified needed data which will be gathered through further record analysis and literature reviews. Finally, an economic model was introduced, and the required uses of the particular data to create such a model was explained.

IV. Findings and Analysis

Introduction

In this chapter, a summary of the findings obtained through use of the methodologies presented in Chapter III are addressed. These findings provided the answers to the investigative questions presented in Chapter I and reemphasized in Chapter III of this report. The results of the research will be discussed by first presenting a method for estimating C&D waste generation at a particular Air Force base. Next, the market factors which affect the feasibility of C&D waste recycling will be discussed. The data needed to perform a comprehensive cost/benefit analysis on C&D recycling options will be reviewed, and finally, a predictive decision model will be offered to help managers determine when it is economically feasible to recycle C&D waste.

C&D Waste Generation Estimates

In order to perform a cost/benefit analysis for C&D recycling, the types and weights of each of the wastes generated must be estimated. This can be done by first determining estimates of the volume of waste generated. This total volume can then be divided into the approximate percentages of each material in the C&D wastestream. Finally, given the densities of each of the materials in the wastestream, the weights of each of the materials in the wastestream can be obtained.

C&D Waste Volume Estimates. As mentioned in Chapter III, several studies have been conducted which attempt to characterize construction and/or demolition wastes on national and regional levels. From a records search of these reports, approximate unit measurements have been found to estimate waste volumes generated. Table 2 lists these unit measurements for the studies discovered during the records search.

Since this thesis calls for the estimation of C&D wastes generated on an Air Force base, the data that is most relevant to this cause is that derived by the Army CERL study. As noted in Chapter III, the authors of this study found that most of the buildings on the military bases sampled were predominantly composed of either concrete/brick or wood. For the purposes of this thesis, the assumption will be made that all structures on the base are either predominantly concrete/brick or wood. Although the Army CERL study failed to include estimators for horizontal demolition, this amount can be adequately estimated for a base by simply determining the volume of the pavements to be demolished and applying an estimating factor for the creation of rubble. For asphalt, the volume of horizontal demolition should be multiplied by 1.33 to attain a realistic volume of asphalt rubble. Similarly, the volume of horizontal concrete demolition should be multiplied by a factor of 1.45 (9:26). Moreover, no estimators are needed for horizontal construction and renovation projects, since they generate a negligible amount of organic or inert waste which are normally used or buried on-site (35).

TABLE 2
PROPOSED ESTIMATORS FOR GENERATION OF C&D WASTES
(3:3, 42:44, 36:42, 10:71, 44:36)

Year	Study	Generation Rates	Remarks
1990	Twin Cities Metropolitan Area	1,400,000 cy/yr	- Location specific - Study offered no insight into predominant variables driving generation rates
1989	State of Vermont	4.7 lbs/person-day	- Study conducted on predominantly rural population. - Study offered no proof of correlation between population size and generation rates.
1986	Berckshire Co, Massachusetts	.93-4.6 lbs/person-day	- Study results were derived from a survey of predominantly residential contractors.
1979	US Army Construction Engineering Research Laboratory, Battelle Labs, Columbus, Ohio	Demolition Wastes: - 3.0 cf waste/sf floor area of masonry structures - 4.5 cf/sf floor area of wooden structures Construction Wastes: - 10% of demolition waste	- Data was collected from 7 large cities, 3 Army Posts, and 1 Air Force Base. - Study offered strong proof of correlation between types of buildings and amount of waste generated.
1979	National Science Foundation, MIT	Demolition Wastes: - 267.5 tons nationally/number of residential demolitions	- Data was collected from 27 cities, small towns, and counties. - Data was only collected from for demolition projects.

C&D Waste Composition. As noted in several studies of the composition of C&D wastestream, the waste composition of vertical C&D waste is a function of many variables such as the age of the structure, the type of structure, and the volume of the waste (48:20, 49:10, 48:12). Most of these reports have concluded, however, that the type of structure is the primary determinant of the material composition (49:10, 48:13, 10:69). Figure 4 shows the results of these studies regarding the composition of the vertical C&D wastestream. For reasons noted in the previous discussion of C&D waste generation studies, the one which most directly applies to the Air Force is the Army CERL Study. Therefore, the results from this study will be used, where applicable. Table 3 lists the material breakout for building demolitions from the Army CERL report. As previously noted, however, this study

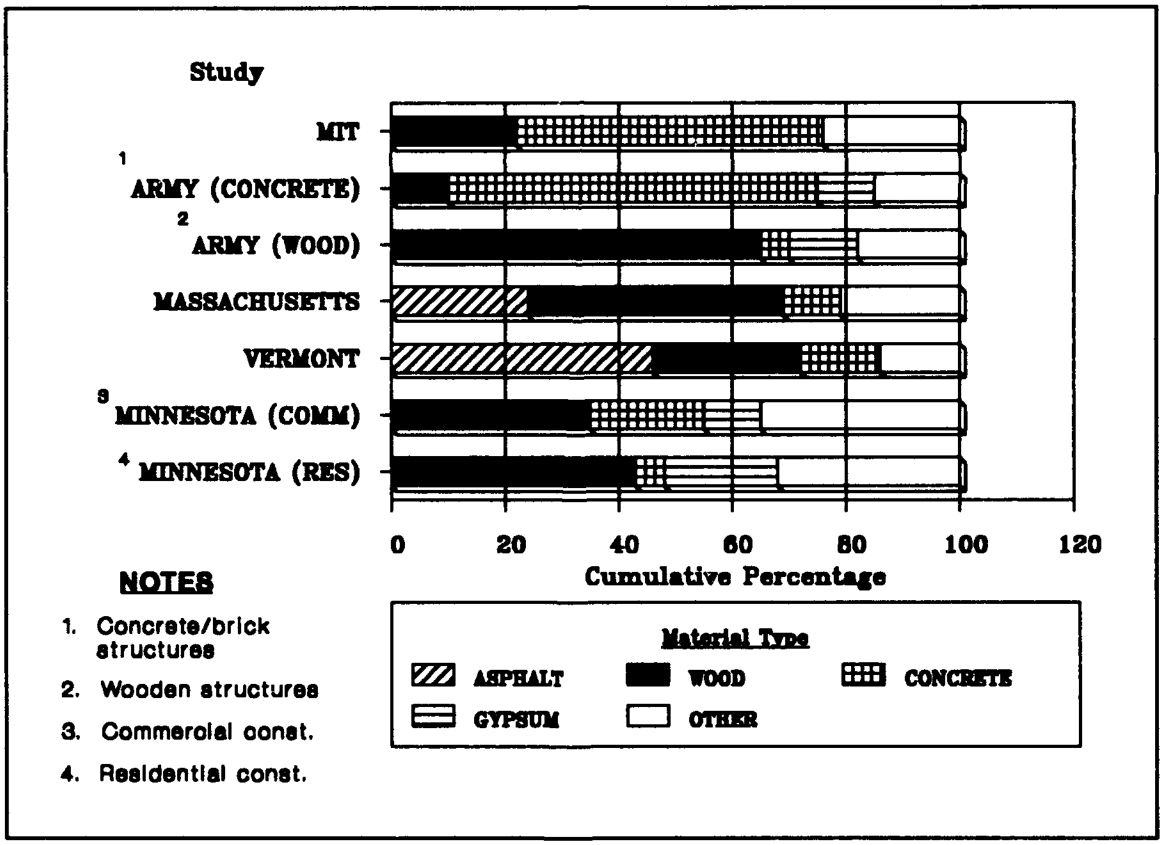


Figure 4. Comparison of C&D Wasteflow Composition Studies
(46:25, 9:11, 44:51, 36:43, 29:4-5)

only concentrated on vertical demolition. Further information is needed to consider horizontal demolition as well as vertical construction and renovation.

The determination of material composition of horizontal demolition is relatively straightforward. The vast majority of the material is either asphalt or concrete. A quick review of old drawings can give a reliable estimate of the percentages of each on projects where both materials were used.

TABLE 3
DEMOLITION WASTE COMPOSITION FROM ARMY CERL STUDY (9:11)

Materials	Percentage According To Type of Structures (%)	
	Concrete/Brick Structure	Wooden Structure
Concrete	65	5
Bricks	10	14
Wood	10	65
Gypsum Board	10	12
Metals	3	2
Other	2	3

The material breakdown for vertical construction and renovation projects differ somewhat from building demolitions. Since the Army CERL study did not provide estimates for these materials, another study must be used. The only study found which looked only at construction and renovation wastes was conducted by the Metropolitan Council of the Twin Cities Area, Minneapolis, MN. The 1993 study, which was published as part of the *Construction Materials Recycling Guidebook*, divided the results into commercial buildings and residential buildings (29:4-5). For the purposes of this study, the assumption is made that the commercial buildings in the Twin Cities report roughly coincide with the concrete and block buildings sampled in the Army CERL study. In turn, the residential building in the Twin Cities report are assumed to approximate materials found in the wooden structures sampled in the Army CERL study. These values can be found in Table 4.

C&D Waste Material Densities. In order to determine approximate weights of the various C&D waste materials generated at a particular base, the material densities must be multiplied by the estimated volumes. These densities were compiled in a related study jointly sponsored by the Minnesota Pollution Control Agency and the Metropolitan Council, Minneapolis, MN. Table 5, an excerpt from their report, lists the densities of the most common C&D wastes.

TABLE 4
CONSTRUCTION WASTE COMPOSITION FROM TWIN CITIES STUDY
(29:4-5)

Materials	Percentage According To Type of Structures (%)	
	Concrete/Brick Structure	Wooden Structure
Concrete	20	5
Bricks	5	1
Wood	35	35
Gypsum Board	10	20
Metals	6	1
Other	24	38

TABLE 5
C&D MATERIAL DENSITIES (20:11)

Material	Avg Density (lbs/cy)	Avg Density (tons/cf)
Wood	333	0.0062
Brick	1,750	0.037
Gypsum Board	1,500	0.028
Metal	500	0.0093
Concrete/Asphalt Rubble	2,500	0.048
Other Waste	648	0.012

C&D Waste Calculations. Given the estimating factors presented in the previous tables, the amount of C&D waste generated annually at a specific Air Force base can be determined by completing the worksheet provided in Appendix A.

C&D Recycled Materials Markets

One of the key ingredients to an economically feasible C&D recycling program is the availability of reliable markets for the recycled product. Results from the available research indicate that existing market conditions for C&D recycled materials are a function of many factors. The two most important factors which govern these markets are geographic location and state and local governmental regulations (23, 32:68, 16:33).

Geographic Location. The geographic location of a base can affect C&D waste recycling markets in a number of ways. Since a large portion of the C&D

wastestream is composed of concrete and asphalt, areas with little rock and gravel resources have excellent markets for these pulverized materials (28:77). As previously mentioned, wood is also a common C&D waste material. Therefore, areas with large power generation plants or factories that use incinerators have a strong market for wood chips as a form of fuel (17:86, 35, 39:52). New markets are also emerging in metropolitan areas for reusable construction and demolition material. Some examples include doors, windows, dimensional lumber, trusses, etc (38:53, 49:115-117).

Government Regulations. Several governmental policies and regulations have worked to restrict the market development of recycled C&D materials. One of the problems a number of recyclers face when dealing with the state and local governments is the determination of what type of permit to obtain for their operations (35, 19:58). For instance, some states do not consider using wood debris as fuel to be recycling. Therefore, different permits are required for recycling facilities that sell their wood product as a fuel (21:77). Additionally, many state, local, and Federal agencies do not allow for recycled materials to be used on their construction projects. This creates a large restriction in the use of recycled concrete and asphalt, since most road work is done for some governmental agency (5:78).

Although state and local officials have been slow to recognize the need to encourage markets for C&D recycled materials, a number of efforts have recently been made (and more are underway) to reverse this trend. A number of state, county, and municipal solid waste departments are developing market guides and wasteflow studies to encourage the development of more C&D waste recycling initiatives in their jurisdiction (23). One such study for the Minneapolis-St. Paul, Minnesota area is included in Appendix B as an example of the information currently being generated by several solid waste departments. Other states currently working on similar projects include New Jersey, Florida, North Carolina, New York, Texas, Vermont, Massachusetts, Washington, and Oregon (23, 35, 32:35, 39:53).

Determining Market Prices for C&D Waste. Although, as noted above, the markets for recycled C&D materials is very location-specific, William F. Cosulich Associates performed a survey in 1991 which led to their report of nationally representative markets and prices for selected recycled C&D materials. The results of their survey, as reported in Resource Recycling, are noted in Table 6 (2:60). This table should be used as a market reference only in the absence of local data. The local data, which may be available from the local solid waste management agency, would provide a more accurate depiction of conditions in the specific area of concern.

Cost/Benefit Analysis

The first step that should be taken to evaluate the costs and benefits of C&D waste recycling is to establish a baseline for the analysis. Once a baseline has been established, the various recycling options should be analyzed. These options include turning the waste over to a recycler-hauler, transporting the material to the nearest recycling facility, or contracting to bring a recycler to the waste, either temporarily for a large construction/demolition project, or on a permanent basis.

TABLE 6
SAMPLE MARKET PRICES FOR RECYCLED C&D MATERIALS (2:60)

Material	Market	Price ($/ton)
Rubble	Asphalt	6- 7
	Fill	4- 6
	Landfill Cover	4- 6
	Riprap	4- 7
	Road Sub-Base	5- 8
Brick	Decorative Purposes	8-15
Clean Shredded Wood		
3"-4" Pieces	Bank Stabilizer	0-15
1"-3" Pieces	Boiler Fuel	10-35
1"-3" Pieces	Bulking Agent	15-20
1"-3" Pieces	Mulch	10-45
1" Pieces	Particleboard	5-20
Gypsum Wallboard	Agricultural gypsum	100
	Wallboard	0- 5
Carpet Padding	Carpet Pads	140
Asphalt Roofing	Parking Lots	2
	Pothole Repair	57
	Asphalt Modifier	60

__Baseline Analysis__. The baseline for disposal of C&D waste should be the do-nothing alternative, which, in most cases, would be to continue disposing of the waste in landfills. In many locations, even the status-quo alternative of landfilling may soon require an economic analysis. As previously mentioned, a number of municipalities across the country are in the process of closing their designated C&D waste landfills.

The decision flowchart noted in Figure 5 can be used to select the cheapest do-nothing alternative.

In all of the alternatives noted in Figure 5, the costs involved are the landfill tipping fees plus the hauling costs. At present, the national median tipping fees for

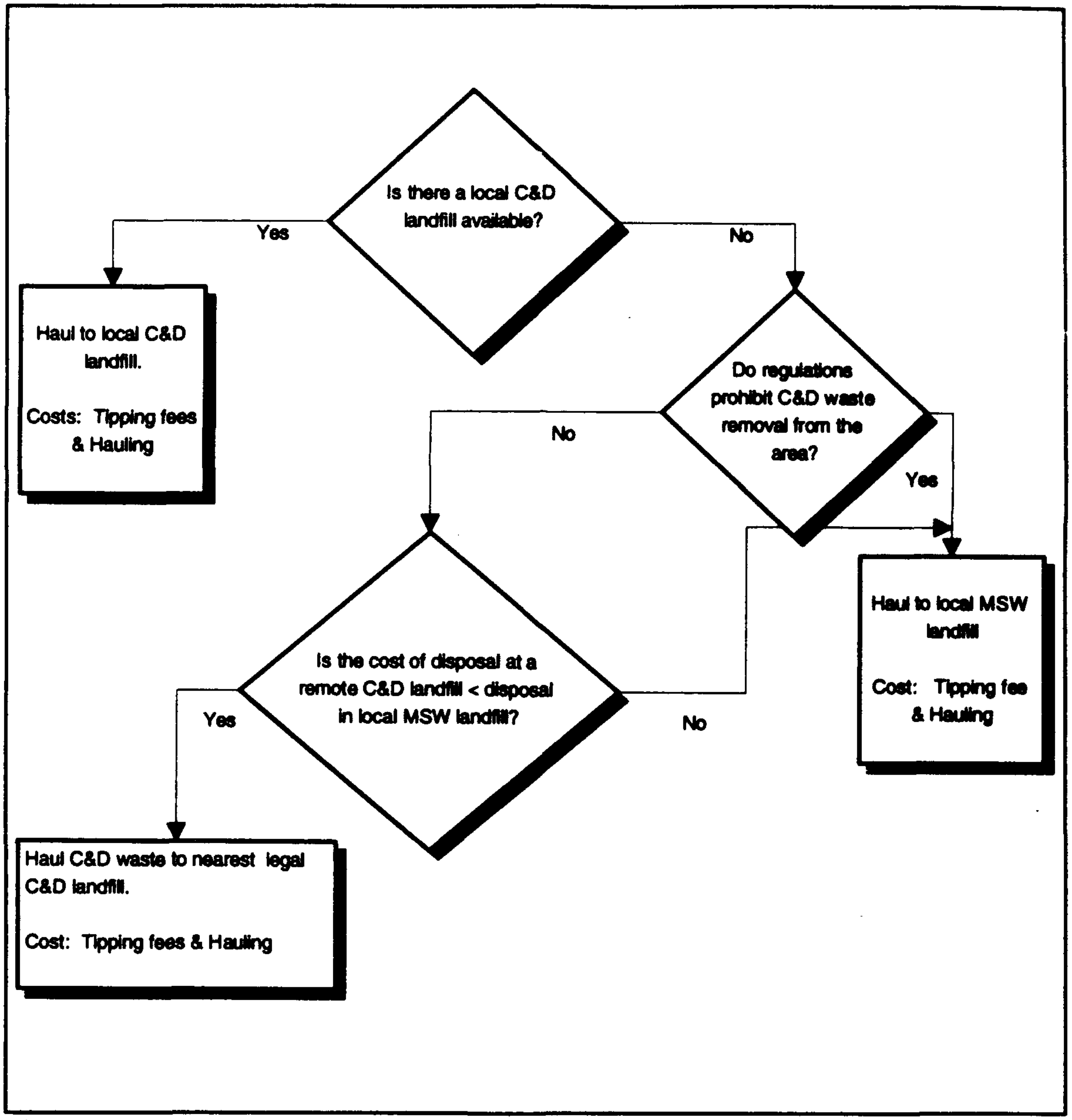


Figure 5. Do-Nothing Alternative Flowchart

C&D landfills are between $26.00 - $32.00/ton, with the costs ranging from a low of $5.00/ton in the Rocky Mountain states to $65.00/ton in the Atlantic and New England states (2:58). These figures, however, are simply representative. The best way to determine information regarding the location, tipping fees, and regulations of local landfills is to contact the local solid waste management office.

The hauling costs are a function of the haul distance, capacity of hauling equipment, loading efficiency, and the material being transported (49:14). The haul distance can be obtained for each option by determining the exact location of the landfill. The capacity of the hauling equipment used in the area and the loading efficiencies can be approximated by contacting some of the local contractors that do work on the base. The volume and weight of the material being hauled can be estimated by using the worksheet provided in Appendix A of this report. Appendix C(A) provides a worksheet to determine the costs of the baseline alternative.

Recycler-Hauler Analysis. In some areas where C&D waste recycling has become established, the recycler-hauler option may be available. A recycler-hauler company will collect all C&D wastes from the jobsite, sort out and process the recyclables and transport them to the appropriate buyers, and transport the remaining unrecyclable waste to a landfill. Typically, these companies charge a fee for their service, and they receive all of the revenues from the sale of the recycled product (35, 29:10). In this case the total cost to the Air Force would be the collection fee from the recycler-hauler. Appendix C(B) provides a worksheet to determine the costs of this alternative.

Transporting Waste to Recycler Analysis. This option can be used in areas where there are C&D recyclers, but no recycler-haulers exist, or when trucks are already available to the Air Force due to the nature of the construction/demolition jobs. In some cases, these recycling facilities will accept commingled waste, which places them with the responsibility for separating the recyclables and disposing of non-recyclables. In most cases, however, these facilities call for separated wastes. In the instance where the recycling facility accepts the entire wastestream, the only costs involved are hauling and tipping fees. In the instance where the waste must be pre-sorted, sorting costs must be considered as well as hauling and tipping fees at both recycling facilities for recyclables and landfills for non-recyclables. Some of the material in this case may bring revenue to the generator. In that case, the revenue must be accounted for as a benefit. Some administrative costs should also be considered for keeping track of the revenues, as well (29:11, 13:31). Figure 6 graphically depicts various cost and benefits which should be considered, depending on the local circumstances. A worksheet is provided in Appendix C(C) to calculate these costs and benefits.

Contract Recycling Analysis. In some cases where local C&D recycling does not exist, it may be beneficial for the Air Force to contract with a recycling company to locate near or on the base and recycle the C&D waste generated. This arrangement may be useful either temporarily for a large demolition/construction operation or permanently if the amount of C&D waste generated annually at that base is substantial enough to support such an operation. In either case, the evaluation of

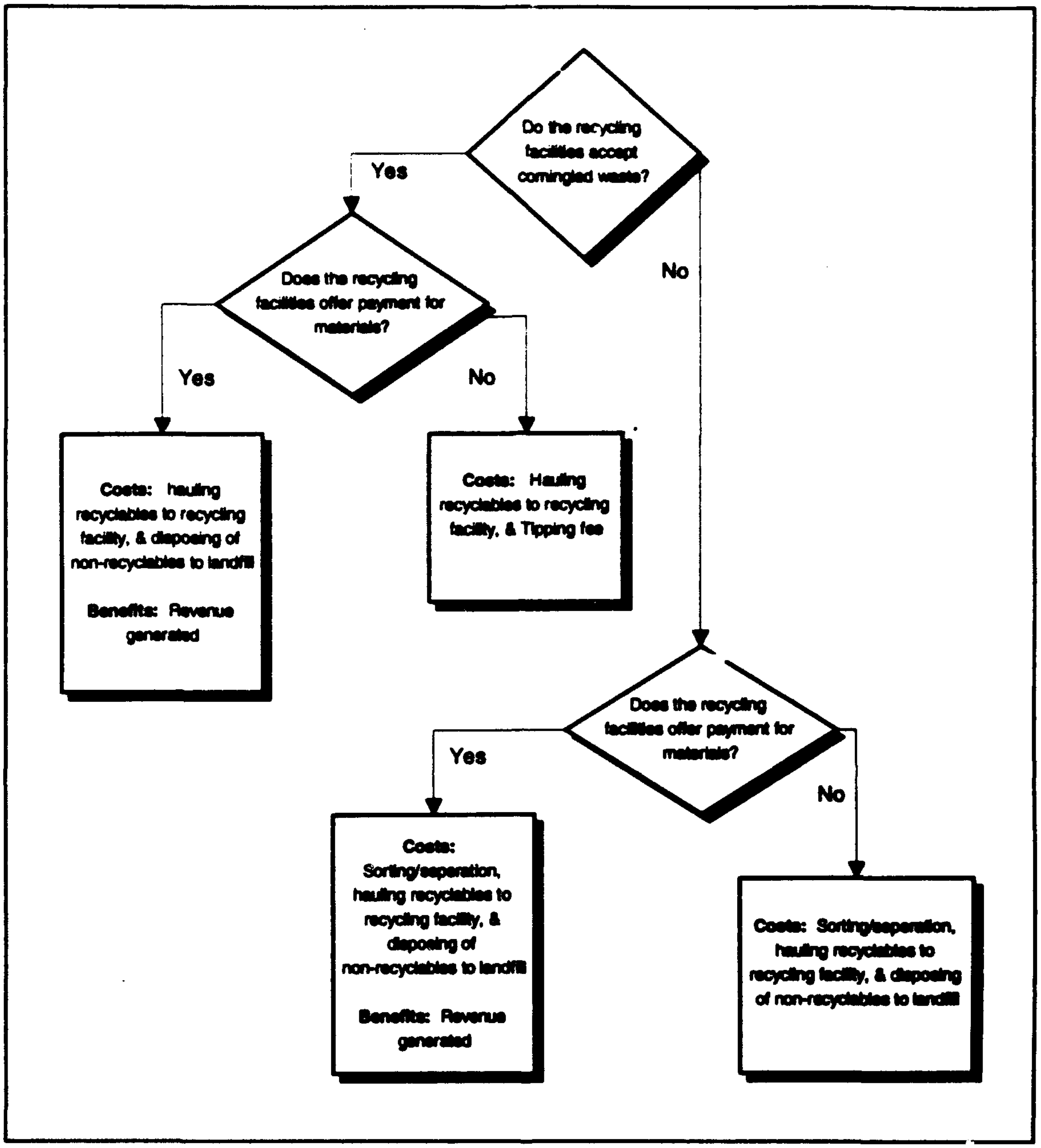


Figure 6. Costs/Benefits when Transporting C&D Waste to Recyclers

the costs and benefits will be the same (35). A worksheet is provided in Appendix C(D) to estimate the costs and benefits of this option.

<u>Costs</u>. The costs to the Air Force will essentially be the cost of the contract. This cost can be estimated by evaluating the potential contractor's cost and adding an overhead and profit margin. It is assumed that typical overhead and profit margins (15% and 10%, respectively) used to estimate construction contracts would be appropriate for this purpose, as well. From the research and discussions with a C&D waste recycler, the contractor's costs can be divided into the following categories for estimating purposes: capital costs, operations and maintenance (O&M) costs, and regulatory costs (35, 8:25-26).

Capital costs are comprised of costs for equipment and facilities. Assuming the contract will be let for full and open competition, a good estimate of the capital costs charged to the project would be the amount of depreciation of the equipment and the required facilities. Although there are a number of methods used to calculate depreciation, the straight line method should be used to estimate a competitive bid, since this method evenly distributes the cost over the useful life of an asset. When the straight line method is used, depreciation over a certain time period is calculated by simply dividing the difference of the historical costs and the salvage values by the useful life of the capital assets as noted in equation (1) below (1:86-87).

$$\frac{HC - SV}{UL} = D \tag{1}$$

where

HC = historical cost ($)

SV = salvage value ($)

UL = useful lifetime (years)

D = depreciation ($/year)

To ensure a conservative estimate of the capital costs, the equipment should be assumed to have a negligible salvage value. Also, from discussions with a C&D recycler, the equipment used can be assumed to have a useful life of five years (35). Furthermore, in an evaluation of 20 C&D waste processing facilities, a linear relationship was found between the daily capacity of the plant and the historical capital costs (2:58). To simplify the determination of capital costs, the assumptions were used to determine annual capital costs of a C&D recycling operation as a function of daily recycling capacity. This relationship is shown graphically in Figure 7.

O&M costs include costs for labor, fuel, utilities, routine maintenance, and landfill disposal of non-recyclables (35, 7:14). The amount of labor at a C&D recycling operation has been estimated to be between 4,000 - 5,000 annual tons per worker (2:58) The typical breakdown of labor specialties for C&D waste recycling is two thirds of the workforce as semi-skilled laborers, and one-third as heavy equipment operators. The labor rates for each of these specialties can be obtained from the local employment office. Fuel, utilities, and routine maintenance has been estimated for a C&D recycling plant to be $5.00 - $7.00 per daily ton (35).

Regulatory costs include expenditures for required permits as well as the environmental testing and monitoring called for in the permits. Some typical costs in

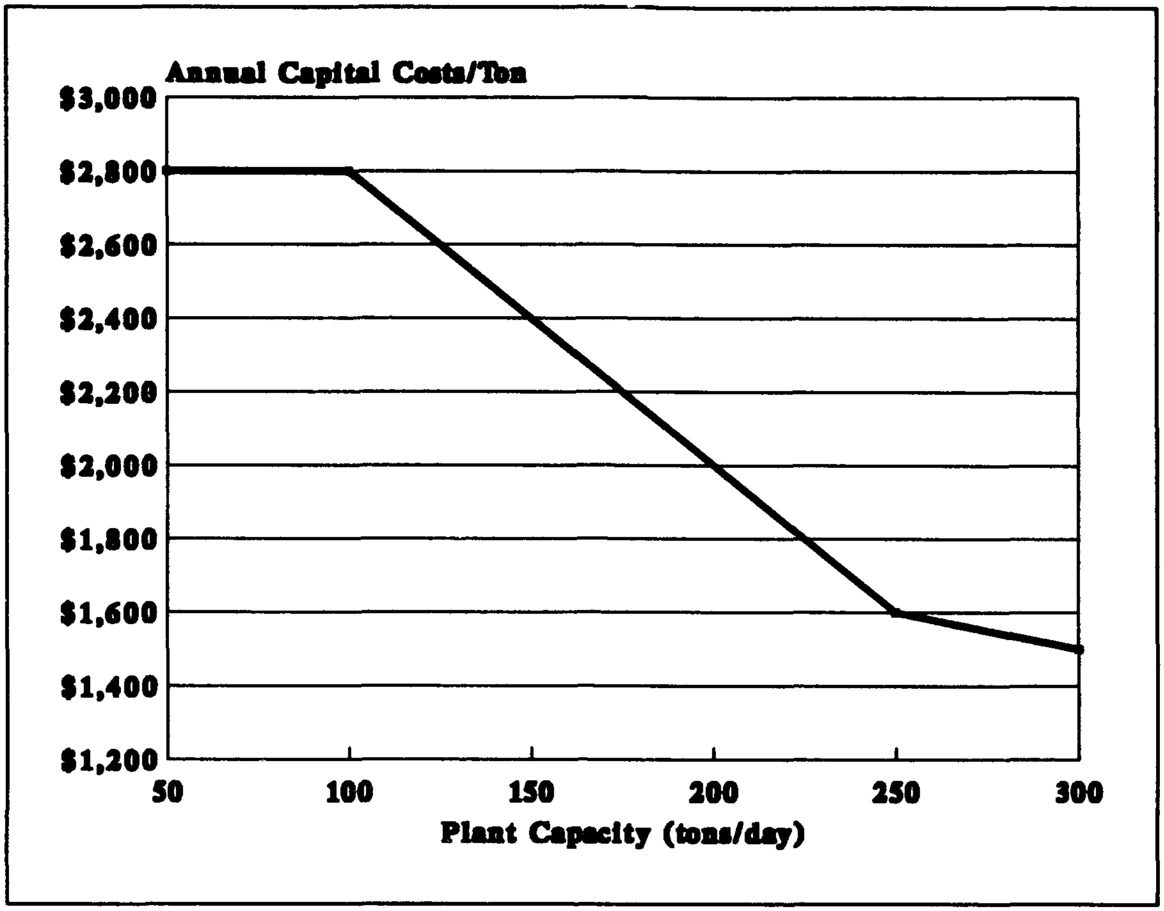


Figure 7. C&D Facility Capital Costs vs Production (2:58)

this category may include engineering designs, test well drilling and groundwater monitoring, air emissions tests, noise emissions tests, etc. The local EPA office should be able to provide the list of requirements and costs for this category (35, 6:34).

<u>Benefits</u>. The tangible benefits from this option are the recycled material gained. These materials can include base course, topsoil, drainage aggregate, wood mulch, scrap metal, dimensional lumber, and wood chips for fuel (2:60). Most of these materials have a use either to the Air Force or to businesses or

residences in the surrounding community. The amount of benefit realized from this material will be a function of base location, base construction activity, and the surrounding community's needs. Therefore, these markets should be looked into to determine price for these materials in the local area. Estimations of the amount of material produced should coincide with the estimations of the different C&D wastes generated.

A Predictive Decision Model

Using the base-specific data from the cost/benefit analyses of the various C&D waste management options, a model can be developed which provides an indication of when it becomes economically feasible to recycle C&D waste. In order to provide a demonstration of this model, a sample base was evaluated. The results from this evaluation will be discussed by first presenting the data obtained from the sample base. This will be followed by a sensitivity analysis for each of the input variables and a selection of the indicator variables. Finally, the generic use of this model at any base will be discussea.

Sample Base Input Variables. In order to demonstrate the model, site-specific information was collected from Hill AFB, Utah for 1994. From this data the input variables, listed in Table 7, were determined. By applying to the flowchart in Figure 5 the information gathered from Hill AFB regarding the cost and location of the MSW and C&D landfills, the baseline alternative in this case was determined to be the disposal of all C&D waste in the local C&D landfill. Also, since reportedly

TABLE 7
INPUT VARIABLES FOR HILL AFB FOR 1994 (14, 25)

Input Variable	**Amount**	**Unit**
1. Estimated area of vertical demolition	114,766	square feet (sf)
2. Estimated portion of the vertical demolition that is primarily concrete structures	20	%
3. Estimated area of vertical construction/renovation	443,300	sf
4. Estimated portion of the vertical construction/renovation that is primarily concrete structures	90	%
5. Estimated volume of horizontal asphalt demolition	50,000	cubic feet (cf)
6. Estimated volume of horizontal concrete demolition	250,000	cf
7. Local C&D landfill tipping fee	8.00	$/ton
8. Local MSW landfill tipping fee	50.00	$/ton
9. Distance from base to local C&D landfill	15	miles
10. Distance from base to local MSW landfill	3	miles
11. Unit cost of hauling C&D debris	14.00	$/truckload-mile
12. Typical wage rates for:		
laborers	7.00	$/hr
equipment operators	12.00	$/hr
13. Delivered material prices for:		
base course	7.00	$/ton
asphalt	10.00	$/ton
wood mulch	10.00	$/ton

there are no existing C&D waste recycling operations in the vicinity, the only recycling option included in the model was contract recycling. As noted by the printout of the analysis for Hill AFB included in Appendix E, the feasibility factor was found to be a negative number, thereby indicating that for the given input variables, C&D waste recycling is not feasible in 1994.

<u>Sensitivity Analysis of Input Variables</u>. Once the model was created, further analysis was conducted to determine the effect independent variance of each input variables has on the recycling feasibility. By performing sensitivity analyses on each of the variables, the value of the feasibility factor in relation to variations in each of the input variables was determined. This analysis was conducted by changing the value of each variable in the spreadsheet model from -100% to 200% of the given amount, while holding all other variables constant. This range was chosen to represent the entire realistically feasible variation of any one variable. These relationships for the data specific to Hill AFB are depicted graphically in Appendix F.

As can be observed from the graphs of the 13 input variables, the variance of only six have any appreciable effect on the economic feasibility of C&D waste recycling. These six input variables are noted below in order of the magnitude of effect the variance of each has on recycling feasibility:

1. Distance from the base to the C&D landfill
2. Unit cost of hauling C&D waste
3. C&D landfill tipping fees
4. Distance from the base to the recycling center
5. Market prices of recycled materials
6. Labor wage rates

Of the six input variables listed above, only the first three have any considerable probability of substantial variance in the foreseeable future. As previously mentioned, C&D landfill regulations are becoming more stringent around the nation (7:15, 49:27). A change in C&D landfill regulations by the State of Utah could cause a large variance in the distance to the C&D landfill and/or C&D landfill tipping fees. In addition, a significant federal fuel oil tax soon may be imposed which could cause a considerable variance in the unit cost of C&D waste hauling (43:136).

The last three input variables, however, have less of a chance of appreciable variance. As can be seen in Appendix E, the distance from the base to the recycling center cannot improve recycling feasibility until the center is virtually next to the construction. Even if the center were located on the base, it would most likely be sited away from the main area of use because of environmental concerns such as excessive dust and noise creation. Furthermore, market prices for recycled materials, as noted before, are not strong (2:60). With the abundance of virgin materials in the Rocky Mountain area, this trend will most likely continue in Utah. Finally, labor wage rates have historically shown little variance beyond the effects of inflation over the past 30 years (42:410), and there is no indication that this will change in the near future.

<u>**Indicator Variables**</u>. The indicator variables in this case are the first three listed above. These three have great potential for increased variance in the near future, and their variance will have the greatest effect on the feasibility of recycling

C&D waste at Hill AFB. By performing manipulations on the spreadsheet shown in Appendix E, two graphs were developed to show when C&D waste recycling is economically feasible, based solely on the three indicator variables. To create the graphs, a *hauling factor* was first created. The hauling factor is the cost of the haul to the landfill minus the cost of the haul to the recycling center. Values for the hauling factor were calculated using different unit hauling costs and distances to the landfill. The relationships between the hauling factor and these two variables are shown in Figure 8. The second graph, presented in Figure 9, was created by

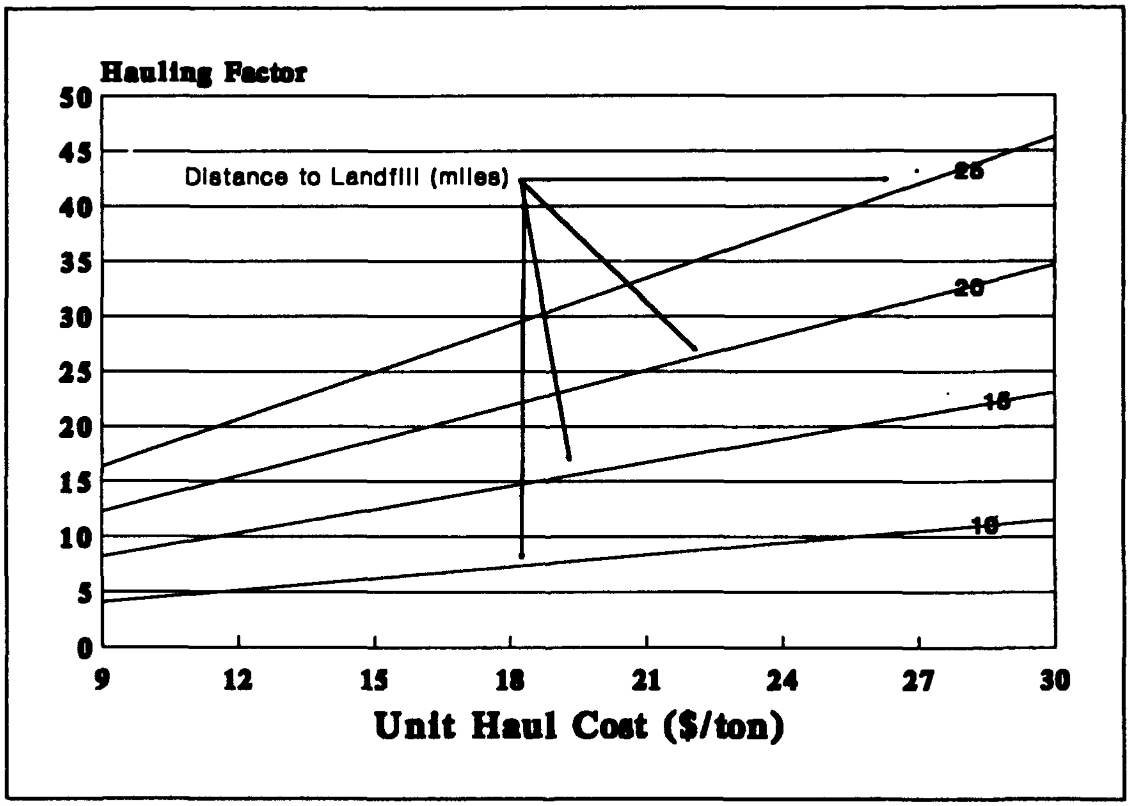


Figure 8. The Relationship of Hauling Factor to Distance to Landfill and Unit Hauling Cost at Hill AFB, Utah

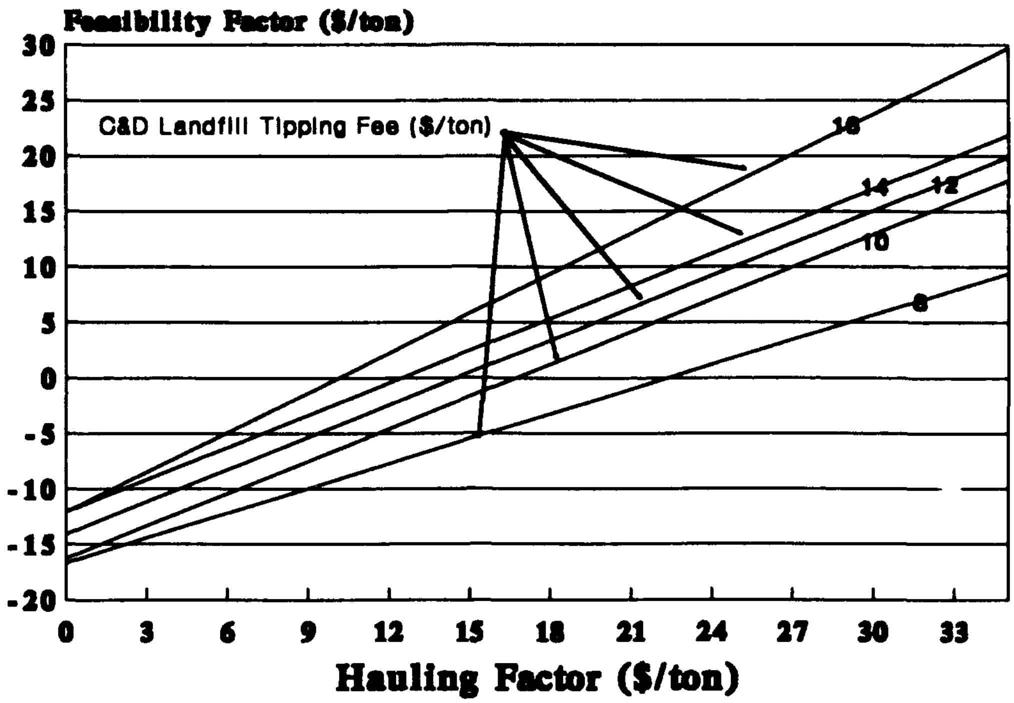


Figure 9. The Relationship of Economic Feasibility of C&D Waste Recycling to Hauling Factors and C&D Landfill Tipping Fees at Hill AFB, Utah

determining values for the feasibility factor given different hauling factors and landfill tipping fees.

<u>Use of the Model for Any Base</u>. The spreadsheet model demonstrated above can be created for any CONUS base by simply following the instructions below each line of the worksheets in Appendix A and C. The lines with no instructions beneath call for the base-specific data which must be collected by the user. Once all of the data is collected, the total number of input variables can be determined. These variables will depend on base-specific circumstances, such as the baseline alternative options as noted in Figure 5 and the recycling alternatives in the area.

The effect of the variance of these variables on recycling feasibility can be determined by performing manipulations noted in Chapter III on the spreadsheet model. From this analysis, the indicator variables can be selected from the input variables. The indicators can then be applied to the spreadsheet model in different combinations and the results graphed as shown in Figures 8 and 9 to create a predictive graph which indicates approximately when C&D recycling can become economically feasible.

A word of caution, however, should be included at this point. Although the indicator variables may be the single most important variables in the model, combinations of the other variables may create a synergistic and/or antagonistic effect on recycling feasibility. For instance, the volume of horizontal concrete demolition and the recycling materials market are not indicator variables for the sample case noted. However, if the volume of concrete waste and the price for recycled base course material drastically increased drastically increased simultaneously, the resulting synergistic effect of the variance could create a pronounced effect on recycling feasibility. Therefore, this model should not be used blindly as a cookbook to determine economic feasibility of C&D recycling. Instead, it should only be used to indicate when it may be worthwhile to accomplish a detailed feasibility study.

Summary

This chapter provided a synopsis of the findings and analyses obtained through the use of the methodologies presented in Chapter III. First, methods were introduced and a worksheet was provided to help Air Force managers characterize and estimate the C&D waste generation at a specific base. Next, the markets for C&D recycled materials was discussed, and a sample of the types of market directories being produced nationwide was provided. Various options were then presented for both C&D waste disposal and recycling alternatives. Worksheets were also provided to calculate the costs and benefits of each applicable option. A predictive model was then presented by encoding the worksheets into a spreadsheet model, and a sample base was selected to apply data to the model to illustrate its usefulness. The use of the model was generalized to any specific base's data, and finally an important limitation of the model was reviewed.

V. Conclusions and Recommendations

Introduction

The purpose of this chapter is threefold. First, this chapter presents a brief summary of the research conducted to create a predictive model for the determination of economic feasibility of C&D waste recycling. Secondly, this chapter will address the practical implications of the development of this model. Finally, this chapter will point out some recommendations for further research on this subject.

Research Summary

Initiatives have been implemented from the Office of the President down to Air Force base-level managers to prevent pollution in the U.S. One initiative being developed at the DoD level is to require C&D waste be recycled when economically feasible. The problem at hand is the development of a method to determine if and when it is economically feasible to recycle this waste at a given location.

Since C&D waste recycling is an emerging industry in some areas of the U.S. today, some limited information on the costs and revenue markets for these operations are available. Additionally, several studies have been conducted which offer estimating factors to determine the amount of C&D waste generated in a certain area. Therefore, the development of a predictive model to determine the feasibility of C&D waste recycling at a given base was possible.

Several steps were taken to develop this model. First, past C&D waste generation studies were reviewed to find estimating factors for generation of the waste that were relevant to typical Air Force base operations. Then, literature reviews and personal interviews were conducted to evaluate the characteristics of the C&D waste recycling markets. Once this data was gathered, methods to conduct cost/benefit analyses were developed and provided for the reader in the form of worksheets. These worksheets also included the required formulas and calculations to create the model. A sample base was then selected and data specific to its location was loaded into the worksheets as a demonstration of the model. Finally, a method was demonstrated to analyze the relationship of the variance of the data to the feasibility of C&D waste recycling.

Practical Implications of the Model

There are three practical uses of the model developed from this research. First, this model can be used to help justify C&D waste recycling at a base. This justification can include an estimate of the cost savings generated by recycling C&D waste. The justification also addresses the increase in C&D waste recycling which can help in the attainment of base recycling goals. Conversely, this model can also be used as support for not recycling where it is not economically feasible. In this capacity, Air Force commanders can be informed of the additional cost to the base of implementing an infeasible program. Finally, this model can be used by Air Force managers to forecast when recycling C&D waste will become cost effective at a base.

This would enable a manager to develop a proactive plan and to implement policies and any required contracts to ensure the creation of a successful recycling program.

Recommendations

Several recommendations are offered to encourage C&D waste recycling in the Air Force and to make the model presented in this report more valid and useful. One way to encourage C&D waste recycling would be to change Air Force construction specifications to allow for use of recycled materials on Air Force construction projects. As a means to this end, research could be conducted which evaluates the costs and benefits of such an initiative. Additionally, the effects that the use of recycled products would have on construction quality could be evaluated.

The model presented in this report assumes the validity and reliability of several estimating factors for C&D waste generation. Research could be conducted to prove the validity of this model. Finally, the usefulness of the model could be improved by developing it into a user-friendly software package. This package could even offer the ability to perform what-if calculations to help the user forecast future conditions.

Appendix A: C&D Waste Generation Worksheet

The following worksheet is designed to help estimate the C&D waste generated at a particular base for a given year. Please refer to C&D Waste Generation Estimates in Chapter IV of this report for further explanations of the estimating factors used in this worksheet.

STEP ONE: Estimate the Amount of Vertical Demolition

1. Estimate vertical demo in square feet (sf)..... 1 _______ sf
2. Estimate percentage of concrete buildings...... 2 _______ %
3. Estimate percentage of wood buildings.......... 3 _______ %
   (2 and 3 should equal 100%.)
4. Total concrete vertical demo................... 4 _______ sf
   (Multiply box 1 by box 2)
5. Total wood vertical demo....................... 5 _______ sf
   (Multiply box 1 by box 3)

STEP TWO: Estimate the Amount of Vertical Construction/Renovation

6. Estimate vertical construction/renovation in square feet.................................. 6 _______ sf
7. Estimate percentage of concrete/brick buildings.................................... 7 _______ %
8. Estimate percentage of wood buildings.......... 8 _______ %
   (line 7 and line 8 should sum to 100%.)
9. Total conc vertical construction/renovation.... 9 _______ sf
   (Multiply line 6 by line 7)
10. Total wood vertical construction/renovation... 10 _______ sf
    (Multiply line 6 by line 8)

STEP THREE: Calculate the Estimated Volumes of Vertical C&D Waste

11. Calculate the volume from concrete vertical demolition................................... 11 _______ cf
    (Multiply line 4 by 3.0 cubic feet (cf)/sf)
12. Calculate the volume from wood vertical demolition................................... 12 _______ cf
    (Multiply line 5 by 4.5 cf/sf)
13. Calculate total demolition volume............. 13 _______ cf
    (Add lines 11 and 12)
14. Calculate the volume from concrete vertical construction/renovation...................... 14 _______ cf
    (Multiply line 9 by .3 cf/sf)
15. Calculate the volume from wood vertical construction/renovation...................... 15 _______ cf
    (Multiply line 10 by .45 cf/sf)

16. Calculate total const/renovation volume....... 16 _______ cf
(Add lines 14 and 15)

STEP FOUR: Estimate the Volume of Horizontal Demolition

17. Estimate volume of asphalt demolition......... 17 _______ cf
(Multiply volume of asphalt laid by 1.33 to obtain rubble volume.)

18. Estimate volume of concrete demolition........ 18 _______ cf
(Multiply volume of concrete placed by 1.45 to obtain rubble volume.)

19. Calculate total volume of horizontal demo..... 19 _______ cf
(Add lines 17 and 18)

STEP FIVE: Calculate the Total Volume of C&D Waste Generated

20. Calculate ..astes generated from horizontal demolition & vertical construction/renovation and demolition............................... 20 _______ cf
(Add lines 13, 16, and 19)

STEP SIX: Estimate Waste Volumes by Material

21. Calculate volume of waste concrete from each operation listed below....................... 21 _______ cf
(Add lines 21.a through 21.e)

21.a. wood vertical demolition............ _______ cf
(Multiply line 12 by 5%)
21.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 65%)
21.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 5%)
21.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 20%)
21.e. concrete horizontal demolition...... _______ cf
(Same as line 18)

22. Calculate volume of waste bricks from each operation listed below....................... 22 _______ cf
(Add lines 22.a through 22.d)

22.a. wood vertical demolition............ _______ cf
(Multiply line 12 by 14%)
22.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 10%)
22.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 1%)
22.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 5%)

23. Calculate volume of waste wood from each operation listed below....................... 23 _______ cf
(Add lines 23.a through 23.d)

23.a. wood vertical demolition............ _______ cf

(Multiply line 12 by 65%)

23.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 10%)

23.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 43%)

23.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 35%)

24. Calculate volume of waste drywall from each operation listed below........................ 24 _______ cf
(Add lines 24.a through 24.d)

24.a. wood vertical demolition............ _______ cf
(Multiply line 12 by 12%)

24.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 10%)

24.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 20%)

24.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 10%)

25. Calculate volume of waste metal from each operation listed below........................ 25 _______ cf
(Add lines 25.a through 25.d)

25.a. wood vertical demolition............ _______ cf
(Multiply line 12 by 2%)

25.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 3%)

25.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 1%)

25.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 6%)

26. Calculate volume of waste asphalt .... 26 _______ cf
(Same as line 17)

27. Calculate volume of other wastes.............. 27 _______ cf
(Add lines 27.a through 27.d)

27.a. wood vertical demolition............ _______ cf
(Multiply line 12 by 1%)

27.b. concrete vertical demolition........ _______ cf
(Multiply line 11 by 2%)

27.c. wood vertical const/renovation...... _______ cf
(Multiply line 15 by 38%)

27.d. conc vertical const/renovation...... _______ cf
(Multiply line 14 by 24%)

STEP SEVEN: Calculate the Weights of the Waste Materials

28. Calculate the weight of waste concrete........ 28 _______ ton
(Multiply line 21 by .048 tons/cf)

29. Calculate the weight of waste bricks.......... 29 _______ ton
(Multiply line 22 by .037 tons/cf)

30. Calculate the weight of waste wood............ 30 _______ ton

(Multiply line 23 by .0062 tons/cf)

31. Calculate the weight of waste drywall......... 31 _______ ton
(Multiply line 24 by .028 tons/cf)

32. Calculate the weight of scrap metal........... 32 _______ ton
(Multiply line 25 by .0093 tons/cf)

33. Calculate the weight of waste asphalt......... 33 _______ ton
(Multiply line 26 by .048 tons/cf)

34. Calculate the weight of other misc wastes..... 34 _______ ton
(Multiply line 27 by .012 tons/cf)

35. Calculate the total weight of C&D waste....... 35 _______ ton
(Add lines 28 - 34)

Appendix B: Sample Market Survey

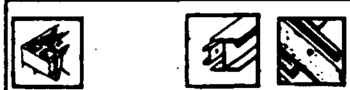
The listing of salvage and reuse organizations, waste haulers, transfer stations, and construction waste processors is intended to provide a representative sample of market directories currently being published in many areas. The inclusion of any company on this list in no way represents an indorsement by the author of the research or the US Air Force.

Multi-material haulers and processors:

Organizations that transport and/or process more than one construction waste material for recycling.

Unless otherwise noted, organizations listed provide waste containers and do not accept deliveries.

1. **Haulers, transfer stations, and MRFs that accept mixed loads of construction wastes and sort out three or more materials forrecycling:**

Materials	Organization Name and Address	Phone Contact	Additional Information	Area Served
	Buckingham Trucking 12444 Hwy 13 Savage MN- 55378	890-9680 Jeff Buckingham	Construction waste hauler. Recycles some plastics, paper, and other materials depending on the job.	South Hennepin, Dakota, Scott
	Disposal Systems, Inc. 915 N Albert St PO Box 4007 St. Paul MN 55104	645-6807 Paul Karsten	Construction and demolition waste hauler, Sorts materials at own yard. Will try to recycle most anything.	Metro Area
	Goodale Transfer 1931 44th St NE Buffalo MN 55313	1-682-2072 Mick Goodale	Construction/ demolition waste hauler. Has recycled cardboard in the past.	Hennepin
	Hilger Transfer 8550 Zachary Lane Maple Grove MN 55369	425-7844 Tim Klatke	Construction waste hauler. Minimum quantity. Also special cleanups, demolition/tear downs.	Hennepin, Anoka, Ramsey others
	Lloyd's Construction Serv, Inc 16860 Welcome Ave SE Prior Lake MN 55372	440-5832 Stephanie or Jim Lloyd	New construction clean-up and smaller scale demolition work and clean-up.	Metro Area

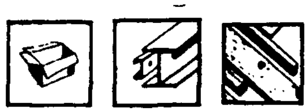
Single Material Recyclers: Organizations that transport and/or process primarily one construction waste material.

Many of the single material recyclers require you to deliver materials to them. All reserve the right to refuse a load if it does not meet their specifications. Your best bet is to call ahead

Materials	Organization Name and Address	Phone Contact	Additional Information	Area Served
Appliances				
Major household appliances (No TVs)	A-Plus Appliance 747 Payne Ave St. Paul MN 55101	298-1929 n/a	Accept drop-offs Monday - Saturday. Hauling service available. Outside Metro, minimum quantity 20 units.	Metro Area
Appliances only	ARCA 2601 Broadway NE ..polis MN 55413	378-1100 n/a	Hauling service available — appliances must be at ground level outside. Drop-offs accepted.	Metro Area
All major appliances, including TVs	Bloomington-Lakeville Appliance 18863 Cedar Ave S Lakeville MN 55044	884-1594 n/a	Accept drop-off. No hauling service available. (Bloomington store has been closed.)	South Metro
All major household appliances, no TVs.	Don Barbeau Appliance 319 W Lake St Mpls MN 55408	827-7019 n/a	Accepts drop-offs.	Mpls and suburbs
All major white goods	JR's Appliance Disposal 8980 Jefferson Trail W Inver Grove Hgts MN 55077	454-9215 n/a	Hauling service available, drop-offs accepted.	Metro Area
Carpet				
Carpet, including rubber-backed and jute-backed, and carpet pad. Must be dry	C.A.R.P.E.T., Inc. PO Box 452 Elk River MN 55330	241-0674 n/a	Provide take-up and/or haul-away service. Call for specifications.	Metro Area
Carpet	Carpet Recovery Innovation 32273 124th st Princeton MN 55371	441-8300 Pete Hovde	Call to arrange drop-off or hauling service.	Metro Area
Carpet and carpet pad. No rubber backed or waffle backed carpet. Must be dry	United Recycling 3119 Lynn Ave S St. Louis Park MN 55416	929-7175 Kim Harrington	Call to arrange drop-off or hauling service.	Metro Area
Concrete, concrete block, and or asphalt				
Clean concrete (no rebar, wire, mesh, brick or asphalt). Clean asphalt (no concrete).	Ashbach Construction Co 299 Olmstead St St. Paul MN 55101	222-1994	Tipping fee for concrete. No fee for asphalt. Call to arrange drop-off. No container or hauling service.	Metro Area
Concrete and asphalt. Rebar and wire mesh okay, but extra charge. Keep concrete and asphalt separate	Barton Sand and Gravel 10633 - 89th Ave N Osseo MN 55369	425-4191 n/a	14 metro area locations. Call to arrange drop-off. No hauling or container service.	Metro Area

Materials	Organization Name and Address	Phone Contact	Additional Information	Area Served
	Materials Recovery, Ltd. 13135 Doyle Path Rosemount MN 55068	437-8618 Craig Gerkin	Materials recovery facility set up to recycle wood and other materials from construction waste loads. No hazardous wastes, liquids, treated lumber, adhesives, or fluorescent bulbs accepted. (Note that this is the case for most of the haulers listed here.)	Metro Area
	North Hennepin Recycling & Transfer 8550 Zachary Lane Maple Grove MN 55369	425-2239 Tim Klatke	Transfer station. Accepts drop-offs. Also accepts oil filters, tree waste (brush) and appliances for recycling.	Metro Area
	Poor Richard's Inc. 400 Whitall St/PO Box 17022 St. Paul MN 55117	776-2323 Kelly Darwin	Transfer station. Also accepts several other materials for recycling.	Metro Area

2. **Haulers, transfer stations, MRFs, and landfills that recycle one or two types of construction materials from mixed loads or transport to recyclers one or more materials that have been sorted on site.**

	AACE Services 1460 Woodhill Rd Burnsville MN 55337	894-7470 Jim Johnson	Small hauling company pulls scrap metal out of mixed loads for recycling and some wood for reuse.	Metro Area
	Ben Oehrlein & Sons & Daughter 10619 Courthouse Blvd. Inver Grove Heights MN 55077	451-1145 Vince Vanella	Transfer station with sorting line. Recycles materials from mixed loads unless load is acceptable at demolition landfill.	Washington, Ramsey, Anoka, Hennepin, Dakota
	Boudreau Roll-Off Inc. PO Box 185 Rockford MN 55373	867-1321 Dayna Boudreau Scrap metal, wood, other	Hauler recycles source-separated scrap metal and some wood. Working on recycling carpeting.	Metro Area
	Cooper's Hauling Mpls	824-6250 Ann Cooper recyc.	Small construction waste hauler. Pulls scrap metal and cardboard from mixed loads for recyc. Some appliance recyc.	Hennepin, Dakota

Appendix C: Cost/Benefit Analyses Worksheets

These worksheets should be used to evaluate the costs and benefits of the various alternatives to landfill disposal of C&D waste. Please refer to Cost/Benefit Analysis in Chapter IV for further explanations of the estimating factors presented in this worksheet.

A. Baseline Analysis

Refer to Figure 5 of this report to determine which costs apply to the local circumstances.

STEP ONE: Determine Tipping Cost

1. Local C&D landfill tipping fee................ 1 _______/ton
2. Local MSW landfill tipping fee................ 2 _______/ton
3. Nearest legal C&D landfill tipping fee........ 3 _______/ton
4. Total weight of C&D waste..................... 4 _______ ton
   (Refer to line 35 of Appendix A.)
5. Local C&D landfill tipping cost............... 5 $ _______
   (Multiply line 1 by line 4.)
6. Local MSW landfill tipping cost............... 6 $ _______
   (Multiply line 2 by line 4.)
7. Nearest legal C&D landfill tipping cost....... 7 $ _______
   (Multiply line 3 by line 4.)

STEP TWO: Determine Hauling Costs

8. Distance to local C&D landfill................ 8 _______ mi
9. Distance to local MSW landfill................ 9 _______ mi
10. Distance to nearest legal C&D landfill........ 10 _______ mi
11. Capacity of hauling equipment................. 11 _______ cy
    (Estimate by contacting local contractors.)
12. Estimated loading efficiencies................ 12 _______ %
    (Estimate by contacting local contractors.)
13. Estimated haul per truckload.................. 13 _______ cy
    (Multiply line 11 by line 12.)
14. Total volume of C&D waste..................... 14 _______ cy
    (Divide line 20 of Appendix A by 27 cf/cy.)
15. Number of truckloads of waste................. 15 _______
    (Divide line 14 by line 13.)
16. Cost of hauling per truckload-mile............ 16 $ _______
    (Estimate by contacting local contractors.)
17. Cost of hauling to local C&D landfill......... 17 $ _______

(Multiply lines 8, 15, and 16.)

18. Cost of hauling to local MSW landfill......... 18 $ ________
(Multiply lines 9, 15, and 16.)

19. Cost of hauling to nearest legal C&D landfill. 19 $ ________
(Multiply lines 10, 15, and 16.)

STEP THREE: Determine Total Cost of Do-Nothing Options

20. Total cost of disposing of C&D waste in local C&D landfill............................ 20 $ ________
(Add lines 5 and 17.)

21. Total cost of disposing of C&D waste in local MSW landfill............................ 21 $ ________
(Add lines 6 and 18.)

22. Total cost of disposing of C&D waste in nearest legal C&D landfill.................... 22 $ ________
(Add lines 7 and 19.)

23. Total cost of most economical option.......... 23 $ ________
(Chose lessor of lines 20 - 22.)

B. Recycler-Hauler Analysis

STEP ONE: Determine Recycler-Hauler Cost

1. Recycler-Hauler fee per ton of waste.......... 1 $ ________
(Contact nearest recycler-hauler for fee.)

2. Amount of waste generated..................... 2 ______ ton

3. Cost of recycling C&D waste through use of the recycler-hauler option............. 3 $ _______

C. Transporting Waste to Recycler Analysis

Refer to Figure 6 of this report to determine which costs apply to the local situation.

STEP ONE: Determine Tipping Costs

1. Recycler(s)'s tipping fee(s) per ton........... 1 $ ________

2. Landfill tipping fees per ton for disposal of nonrecyclables............................. 2 $ ________
(Refer to Appendix C (A).)

3. Amount of material hauled to recycler.......... 3 _______ton
(Refer to STEP SEVEN, Appendix A)

4. Amount of material hauled to landfill.......... 4 _______ton
(Subtract line 3 from Appendix A, line 35.)

5. Recycler tipping costs........................ 5 $ _______

(Multiply line 1 by line 3.)

6. Landfill tipping costs........................ 6 $ ________
(Multiply line 2 by line 4.)

7. Total tipping costs.......................... 7 $ ________
(Add lines 5 and 6.)

STEP TWO: Determine Hauling Costs

8. Distance to recycling center(s)................ 8 _______ mi

9. Distance to landfill.......................... 9 _______ mi

10. Estimated haul per truckload .... 10 _______ton
(Same as Appendix C (A), line 13.)

11. Volume of recyclable waste..................... 11 _______ cy
(Divide the volumes of appropriate material from STEP SIX, Appendix A by 27 cy/cf.)

12. Volume of nonrecyclable waste.................. 12 _______ cy
(Subtract line 11 from line 14, Appendix C (A).)

13. Number of truckloads of recyclables............ 13 _______
(Divide line 11 by line 10.)

14. Number of truckloads of nonrecyclables......... 14 _______
(Divide line 12 by line 10.)

15. Cost of hauling per truckload-mile............ 15 $ ________
(Same as line 16, Appendix C (A).)

16. Cost of hauling to recyclers.................. 16 $ ________
(Multiply lines 8, 13, and 15.)

17. Cost of hauling to landfill................... 17 $ ________
(Multiply lines 9, 14, and 15.)

18. Total hauling cost............................ 18 $ ________
(Add lines 16 and 17.)

STEP THREE: Determine Sorting/Separation Costs

19. Time needed to sort 1 cy of C&D waste......... 19 _______ hr
(Contact local contractors for estimate.)

20. Cost of labor per hour........................ 20 $ _______

21. Total volume of waste generated............... 21 _______ cy
(Same as line 14, Appendix C (A).)

22. Total sorting/separating costs................ 22 $ ________
(Multiply lines 19, 20, and 21.)

STEP FOUR: Determine Benefits from Scrap Revenues

23. Amount of each recyclable material delivered to market:
(Refer to STEP SEVEN, Appendix A.)

a. ____________.... ________ ton
b. ____________.... ________ ton
c. ____________.... ________ ton
d. ____________.... ________ ton
e. ____________.... ________ ton

24. Market value for each of the recyclable materials:

a. ____________.... $________/ton
b. ____________.... $________/ton
c. ____________.... $________/ton
d. ____________.... $________/ton
e. ____________.... $________/ton

25. Revenues from each recyclable material:
(Multiply 23 a-e by 24 a-e, respectively.)

a. ____________.... $________
b. ____________.... $________
c. ____________.... $________
d. ____________.... $________
e. ____________.... $________

26. Total Revenue Generated...................... 26 $ ________
(Add lines 25 a-e.)

STEP FIVE: Determine Total Costs for Transporting Waste to Recycler Option.

27. Cost of recycling C&D waste by hauling to a recycler.................................. 27 $ ________
(Subtract line 26 from the sum of lines 7, 18, and 22.)

D. Contract Recycling Analysis

STEP ONE: Estimate the Capital Costs of a C&D Recycling Operation

1. Estimated C&D waste generation................ 1 ________ ton
(Same as line 35, Appendix A.)

2. Estimated C&D waste generation per day........ 2 ________ ton
(Divide line 1 by 272 working days/year.)

3. Estimated annual capital costs per ton........ 3 $ ________
(See Figure 7 of this report.)

4. Total annual capital costs.................... 4 $ ________
(Multiply line 1 by line 3.)

STEP TWO: Estimate the O&M Costs of a C&D Recycling Operation

5. Number of workers needed for operation........ 5 ________
(Divide line 1 by 4000 tons/worker.)

6. Number of semiskilled laborers................ 6 ________
(Multiply line 5 by .667, round to next highest whole number.)

7. Number of heavy equipment operators........... 7 _______
(Multiply line 5 by .333, round to next highest whole number.)

8. Wage rates for:
   a. Semiskilled laborer................ $ _______/hr
   b. Heavy equipment operator........... $ _______/hr
   (Contact local employment office for wage info.)

9. Hourly labor cost for semiskilled laborers..... 9 $ _______
(Multiply line 9 by line 8a.)

10. Hourly labor cost for heavy eqpt operators..... 10 $ _______
(Multiply line 7 by line 8b.)

11. Total hourly cost of operations................ 11 $ _______
(Add lines 9 and 10.)

12. Total labor cost............................... 12 $ _______
(Multiply line 11 by 2240 hrs/yr.)

13. Hauling distance to recycler................... 13 _______ mi
(Assume a certain distance.)

14. Hauling cost/truckload mile.................... 14 $ _______
(Same as Appendix C (a), line 16.)

15. Total volume of C&D waste...................... 15 _______ cy
(Same as Appendix C (a), line 14.)

16. Estimated haul per truckload................... 16 _______ cy
(Same as Appendix C (a), line 13.)

17. Number of truckloads of waste.................. 17 _______
(Same as Appendix C (a), line 15.)

18. Cost of hauling to contract recycler........... 18 $ _______
(Multiply lines 13, 14, & 17.)

19. Other O&M costs................................ 19 $ _______
(Multiply line 1 by $7.00/ton.)

20. Total O&M costs................................ 20 $ _______
(Add lines 12, 18, & 19.)

STEP THREE: Estimate Regulatory Costs

Contact local EPA and solid waste management agency for information on specific requirements.

21. Permit Costs................................... 21 $ _______

22. Number of monitoring wells required............ 22 _______

23. Cost per monitoring well installation.......... 23 $ _______

24. Cost for monitoring wells...................... 24 $ _______
(Multiply line 21 by line 22.)

25. Number of samples required..................... 25 _______

26. Cost of analysis per sample.................... 26 $ ________

27. Cost of sampling................................ 27 $ ________
(Multiply line 25 by line 26.)

28. Cost of other requirements...................... 28 $ ________

29. Total regulatory costs.......................... 29 $ ________
(Add lines 21, 24, 27, and 28.)

STEP FOUR: Determine Estimated Contract Cost

30. Estimated direct contract costs................. 30 $ ________
(Add lines 4, 20, and 28.)

31. Contractor's estimated overhead................. 31 $ ________
(Multiply line 30 by 15%.)

32. Contractor's estimated profit................... 32 $ ________
(Multiply the sum of lines 30 and 31 by 10%.)

33. Total estimated contract cost................... 33 $ ________
(Add lines 30-32.)

STEP FIVE: Determine Estimated Benefits

34. Types, quantities, and prices of recycled materials produced:
(If the recycled material i~ to be stockpiled and used on the base, the material prices should reflect the savings in hauling costs.)

a.	base course...	________	ton @ $	________/ton	= $	________
b.	asphalt.......	________	ton @ $	________/ton	= $	________
c.	topsoil.......	________	ton @ $	________/ton	= $	________
d.	wood mulch....	________	ton @ $	________/ton	= $	________
e.	wood chips....	________	ton @ $	________/ton	= $	________
f.	dimensional lumber........	________	board-ft @ $	________/board-ft	= $	________
g.	scrap metal...	________	ton @ $	________/ton	= $	________
h.	other........	________	@ $	________/	= $	________

35. Total estimated benefits........................ 35 $ ________
(Add lines 34 a-h.)

STEP SIX: Determine Total Cost of Contract Recycler Option

36. Total cost of contract recycler option......... 36 $ ________
(Subtract line 35 from line 33.)

Appendix D: Data Gathered from Hill AFB, Utah

A. Questions and Responses from BENECO Enterprises

1. **Q:** Are there any public or private landfills in the local vicinity which accept construction debris, but not municipal garbage?

   A: Yes.

2. **Q:** If the answer is yes to #1, what is the fee charged for dumping at these landfills?

   A: $5.00 - $8.00 per ton.

3. **Q:** If the answer is yes to #1, how far away from the base is the closest of these landfills?

   A: Approximately 15 miles

4. **Q:** What does the local MSW landfill charge per ton to dump?

   A: $50.00 per ton.

5. **Q:** How far from the base is the local MSW landfill?

   A: 3 miles.

6. **Q:** Is it legal to haul debris to some other county to dump it?

   A: No, but there are some exceptions, like hauling clean fill and salvageable materials.

7. **Q:** If the answer to question #6 is yes, how far from the base is the nearest place other out of the county you can take construction debris for dumping?

   A: N/A

8. **Q:** What is the cost of hauling debris per truckload-mile?

   A: $10.00 - $15.00 per truckload-mile.

9. **Q:** What is the typical capacity of trucks used to haul construction debris?

   A: Capacity would be 20 to 40 cubic yards, but the realistic loading would be 12 to 14 cubic yards.

10. **Q:** What are the typical wage rates for laborers and heavy equipment operators?

    A: Laborer: $6.00 - $8.00, Equipment Operator: $10.00 - $12.00

11. **Q:** Are there any types of recycling operations for construction and demolition debris in the area (concrete, asphalt, wood, cardboard, etc.)?

    A: No, but there are some contractors who reuse their own material.

12. **Q:** If the answer to question #11 is yes, what type of operations are there?

A: N/A

13. **Q:** If the answer to question #11 is yes, what is their tipping fees?

A: N/A

14. **Q:** If the answer to question #11 is yes, how far from the base are they?

A: N/A

15. **Q:** What are the delivered material prices for base course, asphalt, and wood mulch?

A: $7.00/ton for base course, $10.00/ton for asphalt and wood mulch

B. Questions and Responses from Hill Civil Engineering Squadron

1. **Q:** What is the estimated area of vertical demolition for 1994?

A: 114,766 square feet (sf).

2. **Q:** How much of the demolition noted in #1 is predominantly concrete or brick structures?

A: Less than 20%.

3. **Q:** What is the estimated area of vertical construction and renovation for 1994?

A: 443,300 sf.

4. **Q:** How much of the construction/renovation noted in #3 is predominantly concrete or brick structures?

A: More than 90%.

5. **Q:** What is the estimated volume of horizontal concrete demolition for 1994?

A: 250,000 cubic feet (cf).

6. **Q:** What is the estimated volume of horizontal asphalt demolition for 1994?

A: 50,000 cubic feet (cf).

Appendix E: C&D Waste Recycling Feasibility Model for Hill AFB for 1994

Note: The numbering system for the model correlates with the line numbers in the appropriate worksheet.

I. Values for Appendix A, C&D Waste Generation Worksheet

A. Estimate Area of Vertical Demolition

* 1.	Estimated area of vertical demolition:	114,766 sf
* 2.	% concrete-type structures:	20 %
3.	% wood-type structures:	80 %
4.	Total area of concrete vertical demo:	22,953 sf
5.	Total area of wood vertical demo:	91,813 sf

B. Estimate Area of Vertical Construction/Renovation (C/R)

* 6.	Estimated area of vertical C/R:	443,3[illegible]0 sf
* 7.	% concrete-type structures:	95 %
8.	% wood-type structures:	5 %
9.	Total area of concrete vertical C/R:	421,135 sf
10.	Total area of wood vertical C/R	22,165 sf

C. Calculate Estimated Volumes of Vertical C&D Waste

11.	Volume of concrete vertical demo:	68,860 cf
12.	Volume of wood vertical demo:	413,158 cf
13.	Total demolition volume:	482,017 cf
14.	Volume of concrete vertical C/R:	126,341 cf
15.	Volume of wood vertical C/R:	9,974 cf
16.	Total C/R volume:	136,315 cf

D. Estimate the Volume of Horizontal Demo

*17.	Volume of asphalt demolition:	50,000 cf
*18.	Volume of concrete demolition:	250,000 cf
19.	Volume of total horizontal demo:	300,000 cf

E. Calculate the Total Volume of C&D Waste Generated

20.	Total volume of C&D waste:	918,332 cf

* Indicates the input variables required to operate the model.

F. Estimate Waste Volumes by Material

21.	Waste concrete:	341,183 cf
22.	Waste bricks:	71,145 cf
23.	Waste wood:	323,947 cf
24.	Waste drywall:	71,094 cf
25.	Waste metal:	18,009 cf
26.	Waste asphalt:	50,000 cf
27.	Other waste:	42,954 cf

G. Calculate Weights of Waste Materials

28.	Waste concrete:	16,377 ton
29.	Waste bricks:	2,632 ton
30.	Waste wood:	2,008 ton
31.	Waste drywall:	1,991 ton
32.	Waste metal:	167 ton
33.	Waste asphalt:	2,400 ton
34.	Other waste:	515 ton
35.	Total weight of C&D materials:	25,576 ton

II. Values for Appendix C (A), Baseline Analysis

A. Determine Tipping Cost

* 1.	Local C&D landfill tipping fee:	$8.00 /ton
* 2.	Local MSW tipping fee:	$50.00 /ton
3.	Nearest legal C&D landfill tipping fee:	N/A
4.	Total weight of C&D waste:	25,576 ton
5.	Local C&D landfill tipping cost:	$204,606
6.	Local MSW landfill tipping cost:	$1,278,787
7.	Nearest legal C&D landfill tipping cost:	N/A

B. Determine Hauling Cost

* 8.	Distance to local C&D landfill:	15 miles
* 9.	Distance to local MSW landfill:	3 miles
10.	Distance to nearest legal C&D landfill:	N/A
11.	Capacity of hauling equipment:	30 cy
12.	Estimated loading efficiency:	50 %
*13.	Estimated haul per truckload:	15 cy
14.	Total volume of C&D waste:	34,012 cy
15.	Number of truckloads of waste:	2,267

* Indicates the input variables required to operate the model.

*16.	Cost of hauling per truckload mile (T):	$14.00 /T
17.	Cost of hauling to local C&D landfill:	$476,172
18.	Cost of hauling to local MSW landfill:	$95,234
19.	Cost of hauling to nearest legal C&D landfill:	N/A

C. Determine Costs of Do-Nothing Options

20.	Total cost using local C&D landfill:	$680,778
21.	Total cost using local MSW landfill:	$1,374,021
22.	Total cost using nearest legal C&D landfill:	N/A
23.	Cost of most economical option:	$680,778

III. Values for Appendix C (D), Analysis of Contractor Recycling Option

A. Estimate the Annual Capital Costs

1.	Estimated C&D waste generation:	25,576 ton
2.	Estimated C&D waste generation per day:	[illegible]ntn/dy
3.	Estimated Capital costs per ton:	$14,000.00 /ton

4.	Total annual capital costs:	$263,280

B. Estimate the Annual O&M Costs

5.	Number of workers needed for operation:	6
6.	Number of semiskilled laborers:	4
7.	Number of heavy equipment operators:	2
* 8.	Wage rates for:	
	a. semiskilled laborer:	$8.00 /hr
	b. heavy equipment operator:	$10.00 /hr
9.	Hourly labor cost for semiskilled laborers:	$34.10 /mhr
10.	Hourly labor cost for heavy equipment operators:	$21.31 /mhr
11.	Total hourly cost of operations:	$55.41 /mhr
12.	Total labor cost:	$124,128
*13.	Hauling distance to recycling operations:	5 miles
14.	hauling cost/truckload-mile:	$14.00 /T
15.	Total volume of C&D waste:	34,012 cy
16.	Volume of truck capacity:	15 cy
17.	Number of truckloads:	2,267
18.	Total hauling cost to recycler:	$158,724
19.	Other O&M costs:	$179,030
20.	Total O&M costs:	$461,882

C. Estimate Regulatory Costs

*21 - 29.	Permit costs:	$30,000

* Indicates the input variables required to operate the model.

D. Determine Estimated Contract Costs

30.	Estimated direct contract costs:	$755,162
31.	Contractor's estimated overhead:	$113,274
32.	Contractor's estimated profit:	$86,844
33.	Total estimated contract cost:	$955,279

E. Determine Estimated Benefits

*34. Delivered prices and amounts of each of the following:

a.	base course	13,920 ton	@ $7.00/ton	= $97,442
b.	asphalt	1,800 ton	@ $10.00/ton	= $18,000
c.	wood mulch	1,004 ton	@ $10.00/ton	= $10,042

35.	Total Estimated benefits:	$125,484
36.	Total cost for this option:	$829,795

IV. Variance Factor Calculations

A. Determine Haul Factor

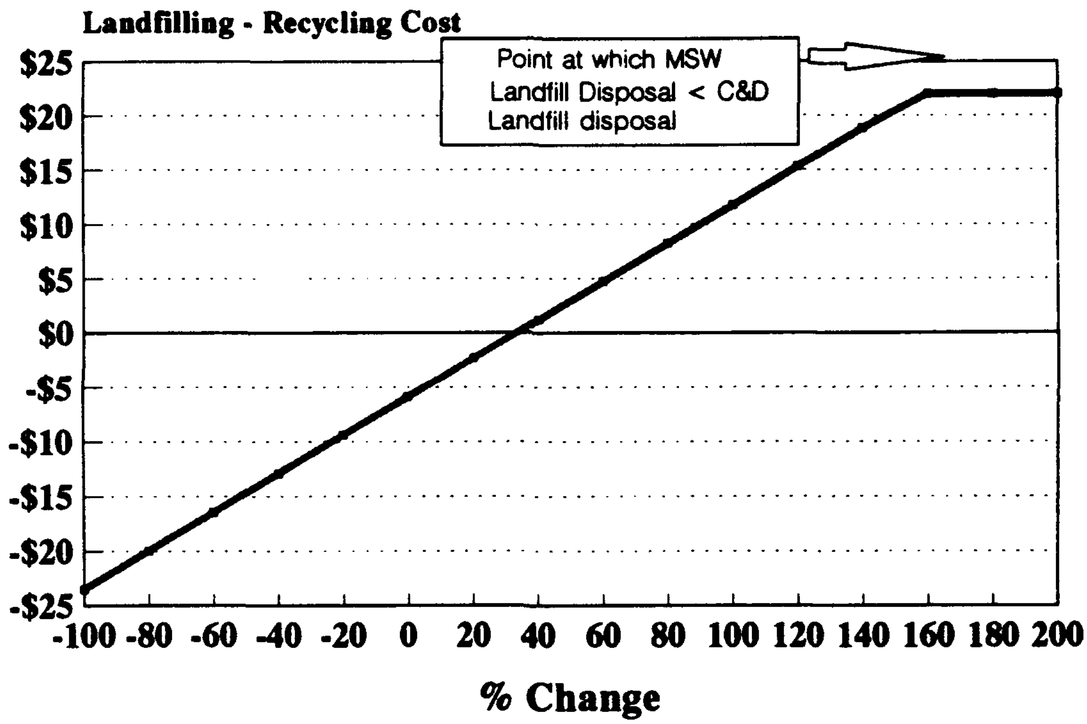
1.	Landfilling haul cost - recycling haul cost:	$9.33 /cy

B. Determine Feasibility Factor

2. Most economical landfill option cost - Most economical recycling option cost: ($5.83)/ton

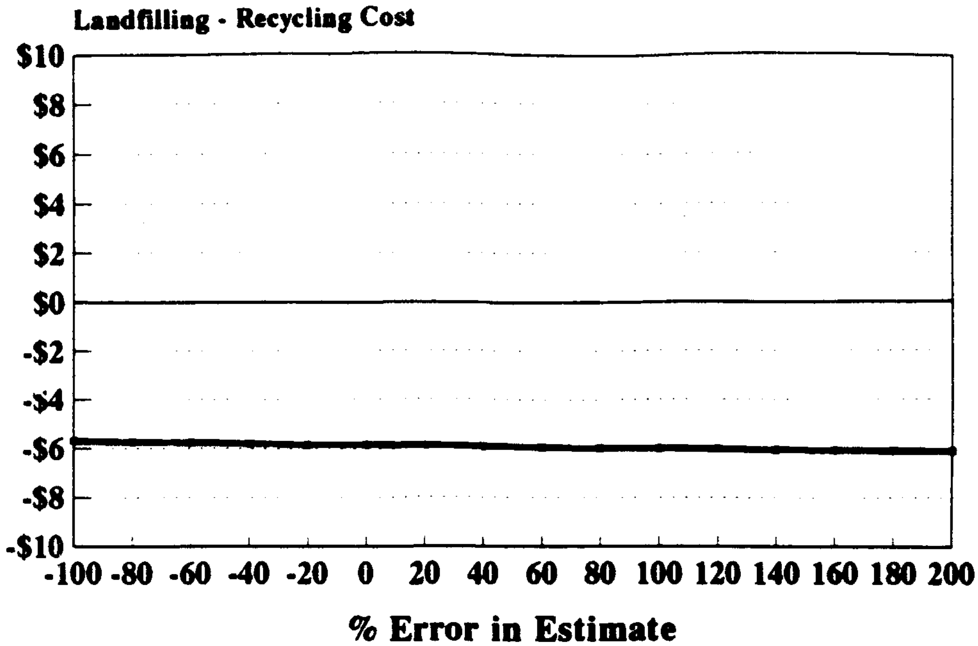
* Indicates the input variables required to operate the model.

Distance to C&D Landfill



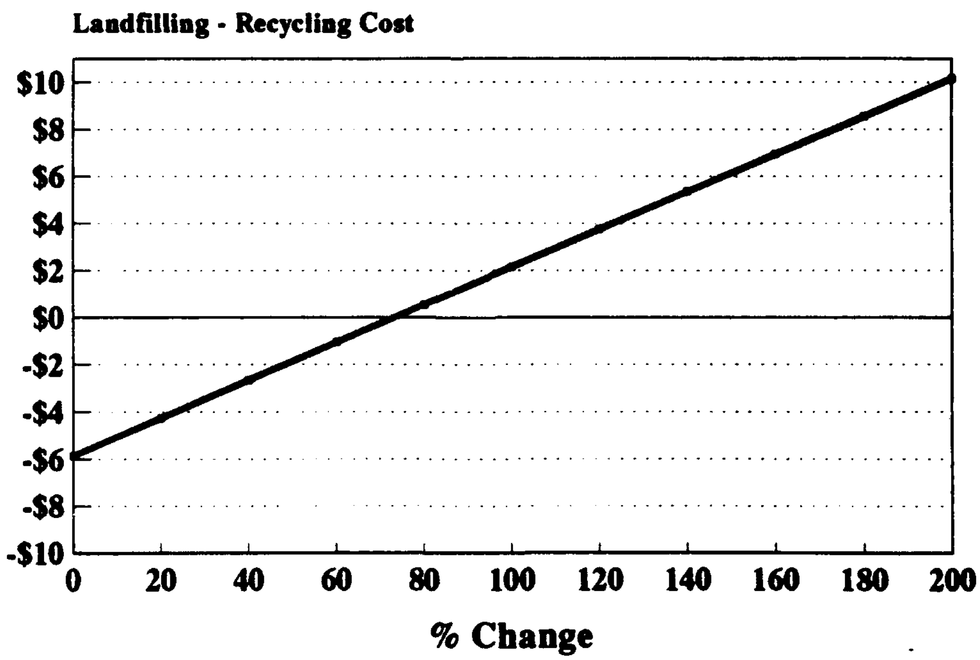
0% Change = 15 miles

Concrete Horizontal Demolition Estimate



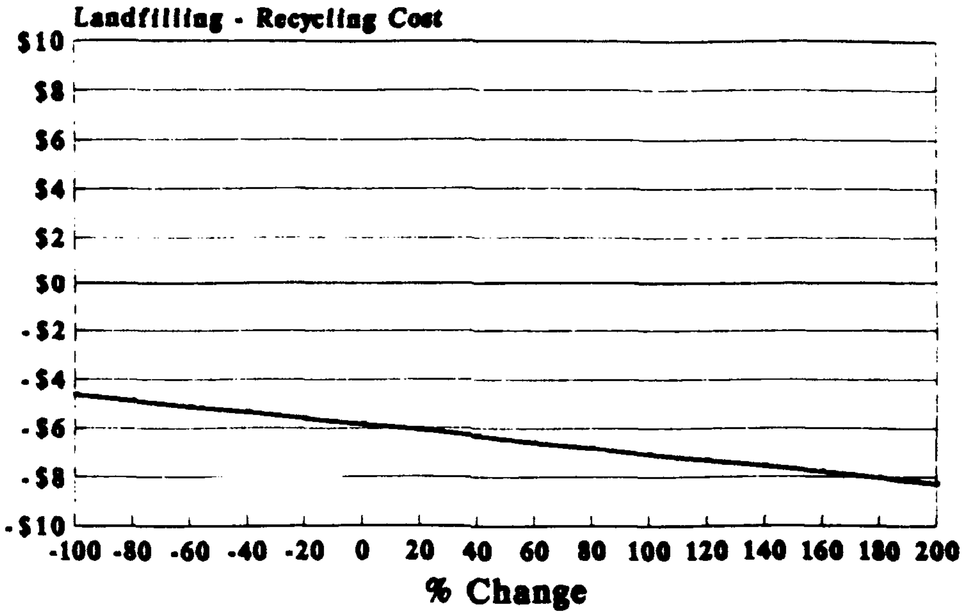
0% Error = 50,000 cf

C&D Landfill Tipping Fees



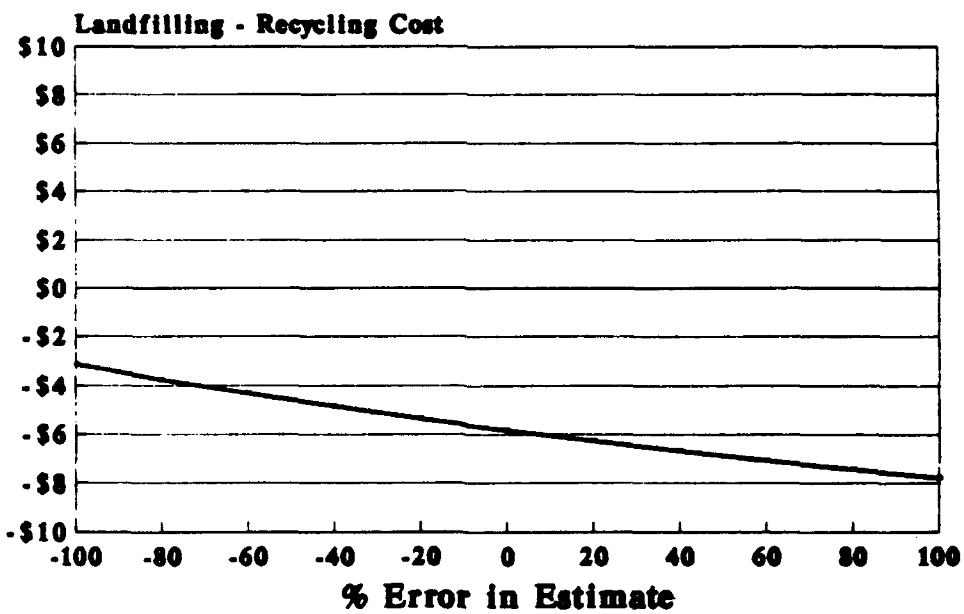
0% Change = $8.00/ton

Estimated Regulatory Costs

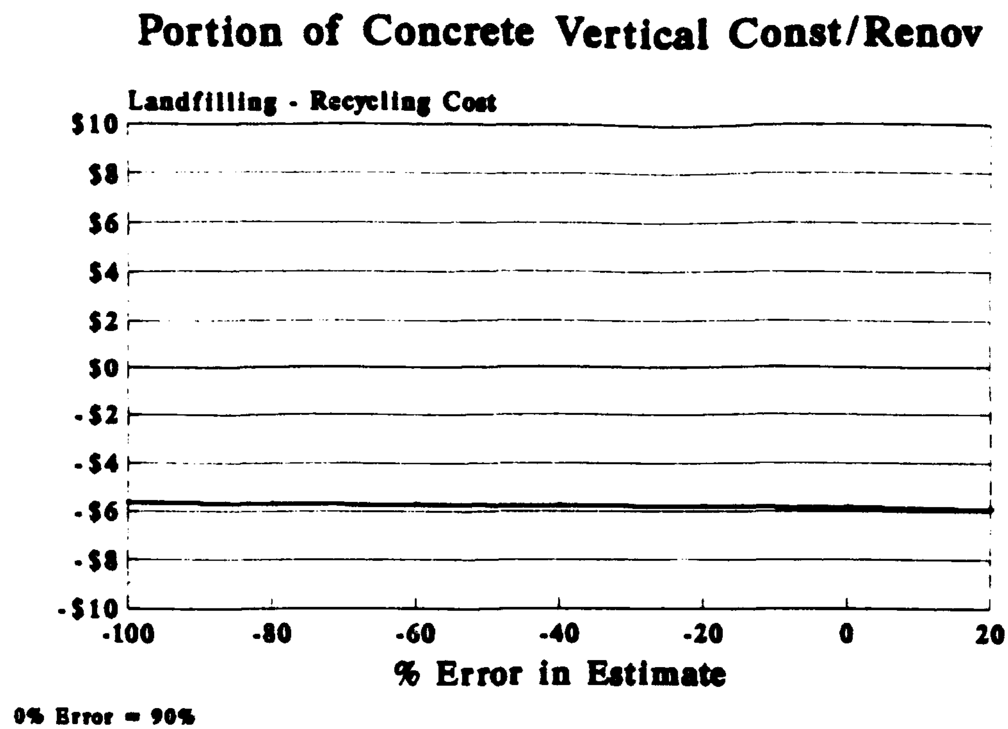


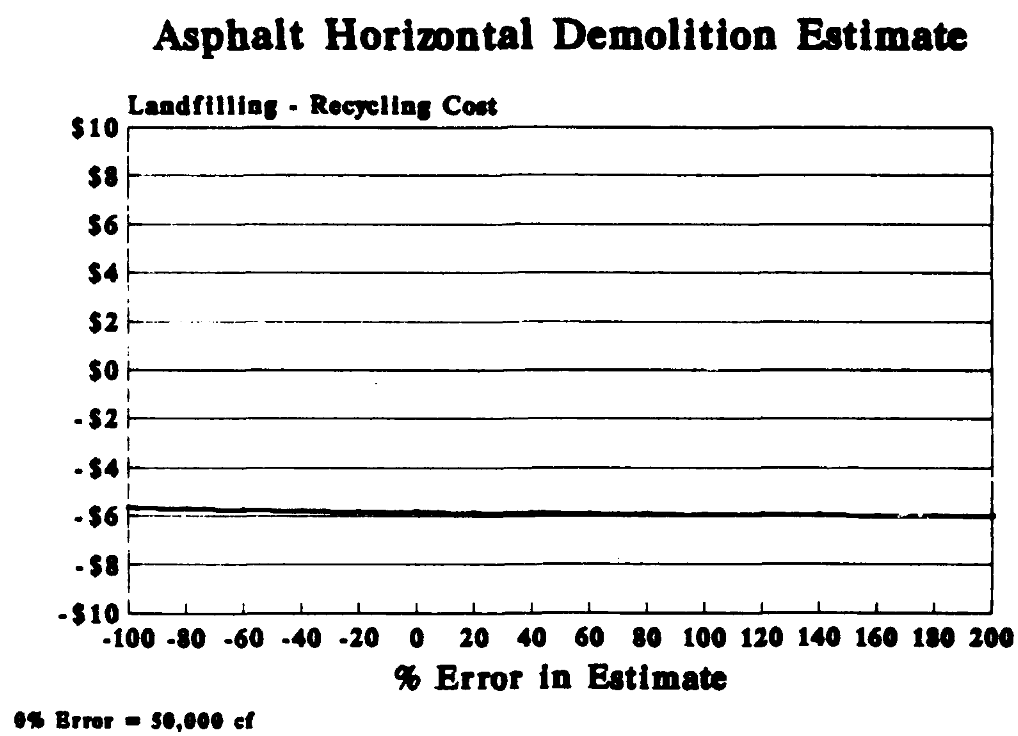
0% = 30,000

Portion of Concrete Vertical Demolition

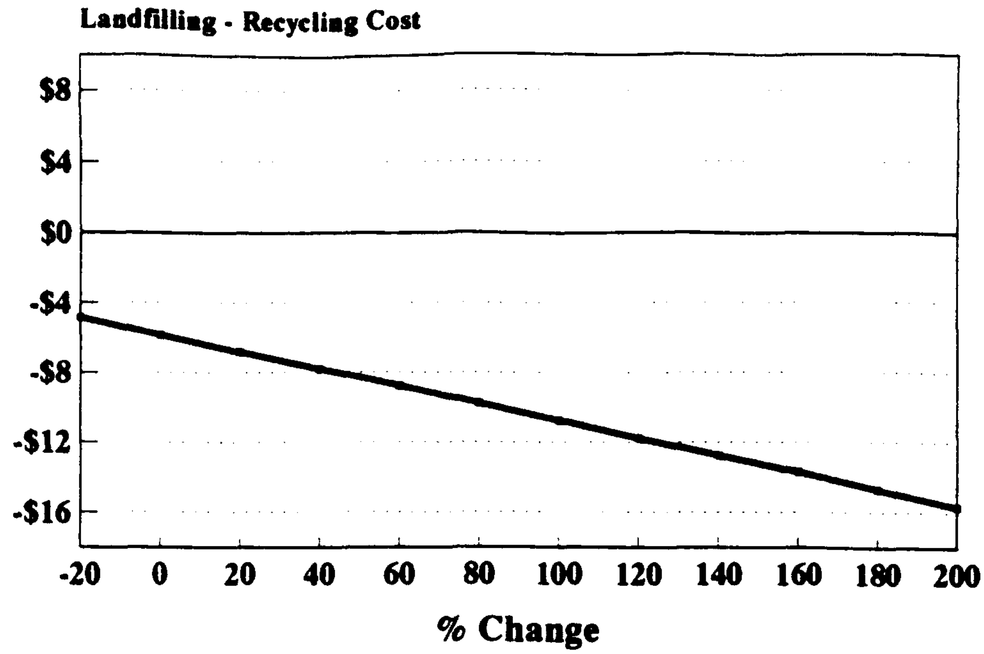


0% Error = 20% Concrete Demolition


Portion of Concrete Vertical Const/Renov
Landfilling - Recycling Cost
$10
$8
$6
$4
$2
$0
-$2
-$4
-$6
-$8
-$10
-100
-80
-60
-40
-20
0
20
% Error in Estimate
0% Error = 90%

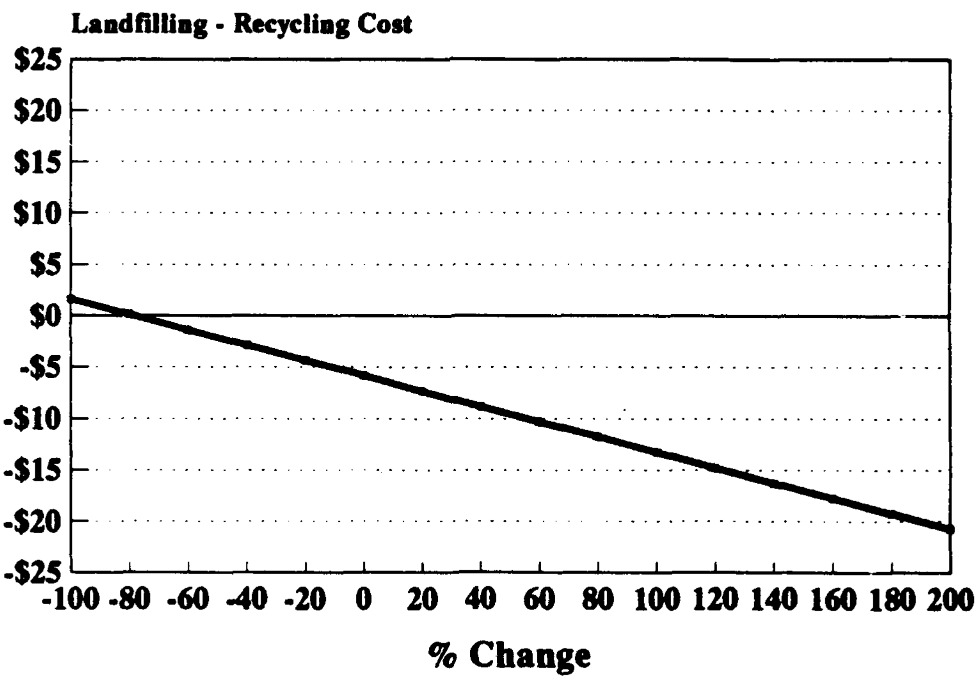

Asphalt Horizontal Demolition Estimate
Landfilling - Recycling Cost
$10
$8
$6
$4
$2
$0
-$2
-$4
-$6
-$8
-$10
-100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180 200
% Error in Estimate
0% Error = 50,000 cf

Labor Wage Rates



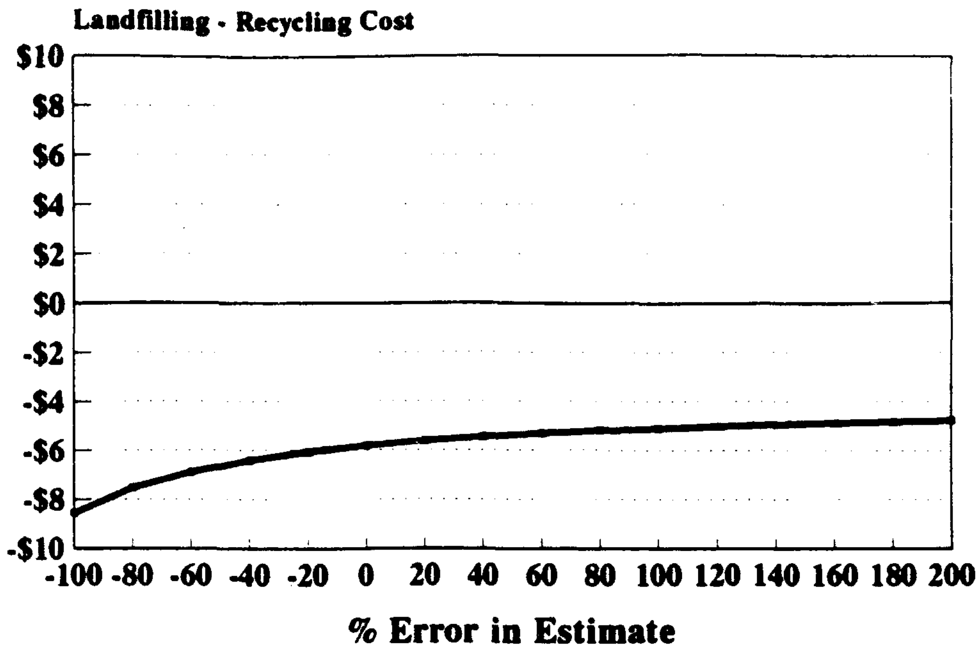
0% = $8/hr (laborer) & $10/hr (operator)

Distance to Recycling Center



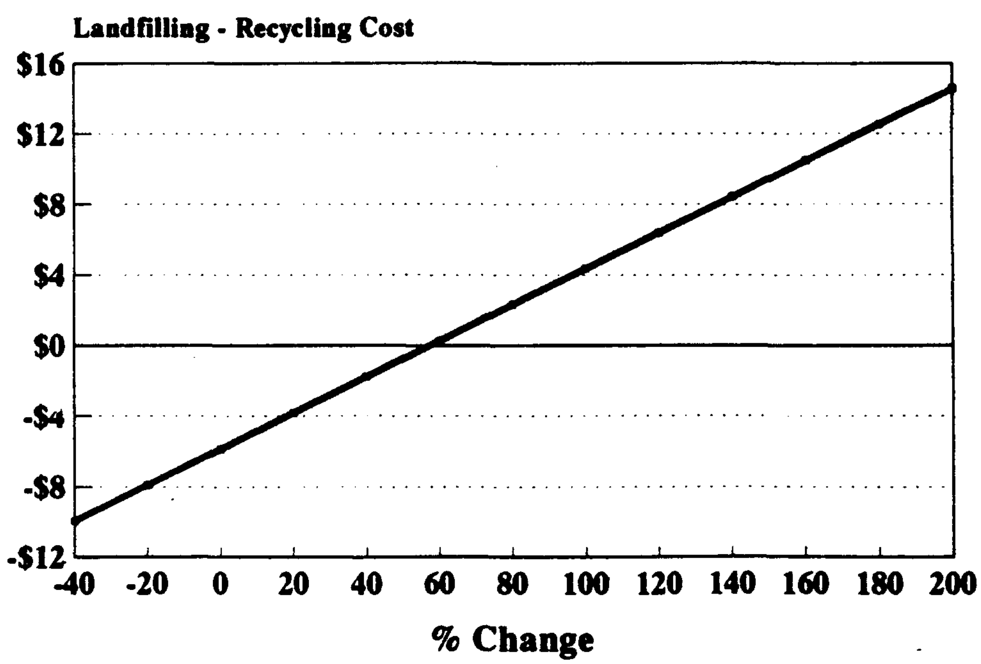
0% Change = 5 miles

Estimate of Vertical Demolition Area



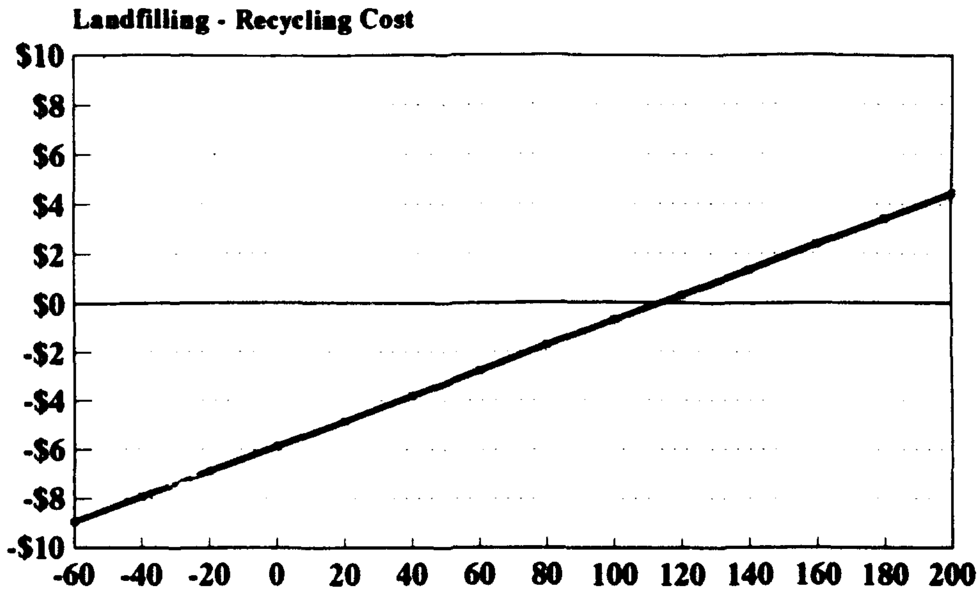
0% Error = 114,766 sf

Cost of Haul/Truckload-Mile



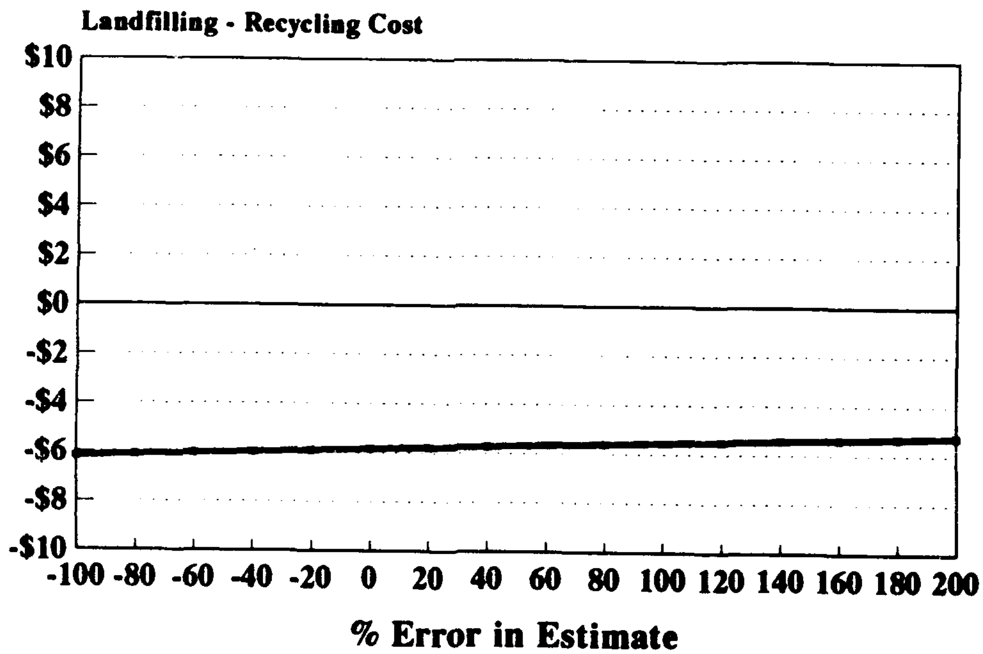
0% = $14.00/truckload-mile

Recycled Materials Market Prices



0% = $7/ton base course, $10/ton asphalt , $10/ton wood mulch

Est of Vertical Const/Renovation Area



0% Error = 225,000 sf Const/Renovation

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Vita

Captain Byron L. Dixon was born on 1 July 1964 in Gulfport, Mississippi. He graduated from Bay High School in Bay St Louis, Mississippi in 1982 and attended the University of Mississippi, graduating with a Bachelor of Science in Civil Engineering in December, 1986. Upon graduation, he received a commission through the USAF Reserve Officer Training Corps and served his first tour of duty at Hill AFB, Utah. He began his Air Force career as a Civil Design Engineer for the 2849th Civil Engineering Squadron, where he was responsible for designs of several base facility construction projects. In November 1988, he was selected to serve as the Civil Engineering Operations Executive Officer until September 1989 when he was appointed Chief of the Simplified Acquisition of Base Engineering Requirements (SABER) construction unit. As Chief of SABER, he was responsible for the management of an $11 million cradle-to-grave design/construction program. Captain Dixon was in charge of the SABER unit until May 1992, when he became a Masters Candidate in the Environmental and Engineering Management Department, School of Engineering, Air Force Institute of Technology.

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13. ABSTRACT *(Maximum 200 words)*

This study created a model to be used at a CONUS Air Force base to determine the econimic feasibility of Construction and Demolition (C&D) waste recycling. Three areas were investigated to develop this model: the methods to determine the amounts and types of C&D waste generated at a specific location, the markets for recycled C&D wastes, and the recycling methods currently available. From this data, gathered through records searches and interviews, a procedure was developed to perform cost/benefit analyses on the available recycling options. A model was then created based on these calculations which can arm a manager with information to either support or reject a recycling program by indicating cost savings or losses from recycling C&D waste. Also, the model aids managers in determining the approximate quantities of recyclable materials being generated, which could be valuable in reaching base recycling goals. To demonstrate the model, the feasibility of recycling C&D waste at Hill AFB, UT in 1994 was evaluated. In addition to determining recycling feasibility, a method was presented to perform sensitivity analyses on the base-specific input variables. This procedure can help determine when it will become feasible to create a C&D waste recycling program.

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