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Using Manual Sorting Methods:
A Michigan State University Case Example

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UNIVERSITY WASTE CHARACTERIZATION
USING MANUAL SORTING METHODS:
A MICHIGAN STATE UNIVERSITY CASE EXAMPLE

By

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ABSTRACT

UNIVERSITY WASTE CHARACTERIZATION USING MANUAL SORTING METHODS: A MICHIGAN STATE UNIVERSITY CASE EXAMPLE

By

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This study was conducted to provide a manual sorting model for characterization of university solid waste streams, using Michigan State University as an example. Analyzing university waste streams provides a unique challenge, as universities have some of the characteristics of both municipal and industrial waste streams, but are more difficult to successfully quantify using either materials flow methodologies or per-capita estimations. If universities are to meet state and national waste reduction goals, characterizing the components of the waste stream is an essential first step in planning integrated waste management strategies.

The Michigan State University campus buildings were divided into three strata based on the population characteristics of different segments of the campus: residence halls, university apartments, and academic/administrative facilities. A minimum of twenty 80-200 pound samples were taken from each of these three waste streams within a two week period both summer and fall semesters, 1994. The samples were manually sorted into nine general material categories and the weights of each were recorded. The weights

from these samples were aggregated and analyzed to provide information about the potential diversion rates for commonly recycled materials. With the addition of information from existing campus recycling programs, the university waste streams were compared to the EPA/Franklin materials flow model for municipal waste streams to highlight differences in composition.

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CHAPTER ONE:

INTRODUCTION

In 1971, William Small wrote a book entitled "The Third Pollution," enumerating the concern with solid waste disposal and its impact on the environment, as well as the loss of resources represented by landfilling or incinerating materials. He included a quotation from then Senator Edmund Muskie saying in part:

> If we are to preserve and enhance the quality of our environment, we must find ways to reduce the quantities of solid waste and lessen the burden on our air and water resources. (p. 90)

The country as a whole has struggled with this sentiment for over 20 years, agreeing with Muskie in principle, but finding it difficult to put his words into action. The history of solid waste legislation illustrates this struggle to find ways to lessen the environmental burden as well as the risk to human health. The first major legislative response to increasing amounts of consumer and industrial waste was the Solid Waste Disposal Act (SWDA) of 1965, which encouraged more environmentally sound methods for waste disposal. Responsibility for solid waste programs was shifted in 1970 from the Department of Health, Education, and Welfare (HEW) to the newly-created Environmental Protection Agency (EPA). The Resource Recovery Act, passed the same year, provided some financial support for solid waste initiatives as well as urging the recovery of energy and materials as part of effective waste management programs. Until the passage of the 1976 amendment titled the Resource Conservation and Recovery Act (RCRA), however, solid waste was still seen primarily as a local issue. Continuing concern over the environment and human health prompted the federal legislature to include as part of RCRA the involvement of the EPA in the regulation of waste disposal facilities, both for municipal solid waste and for hazardous waste. The primary goals of RCRA were to:

> 1) protect human health and the environment from the potential hazards of waste disposal,
> 2) conserve energy and natural resources,
> 3) reduce the amount of waste generated, including hazardous waste, and
> 4) ensure that wastes are managed in an environmentally sound manner.
> (Christensen, 1991, p. 569)

From these goals emerged a "waste management hierarchy," a list of waste management alternatives ordered by their ability to conserve resources and protect human health and the environment. Listed from greatest perceived benefit to least, the hierarchy includes: source reduction, reuse of materials, recycling (and composting), incineration, and landfilling. (Young, 1994) Despite the goals of RCRA, and continuing legislative efforts to reclaim more of the materials used in this country, about 75% of the nation's waste stream is still being landfilled. (Wagner, 1995)

The greatest benefit, for both the environment and the economy, is to produce less waste in the first place. Source reduction, the reduction or elimination of waste prior to generation, can be accomplished in several ways. (WMI, 1990) One approach is simply to reduce the amount of waste being generated, through improvements in manufacturing or packaging technology and more careful inventory practices. Source reduction can also address waste toxicity by promoting the replacement of a manufacturing material known to adversely affect human health with one that is less toxic. A third source reduction strategy is the manufacture and purchase of products with a longer useful life, to decrease the proliferation of one-use disposable consumer goods. Source reduction strategies can reduce the amounts of hazardous materials that must be disposed of or otherwise managed to reduce the risk to human health and the environment. (Williams, 1990)

The second step in the waste hierarchy, reuse of materials, is generally defined as using a discarded item again for the same purpose it was originally intended. Examples are the reuse of shipping containers or wooden pallets, as well as finding "new homes" for outdated machinery instead of discarding it. This has benefits both for the company that avoids disposal fees and the recipient of the still-useful good, who avoids the capital outlay necessary to purchase a newer version. Although the materials will eventually need to be discarded, reusing items instead of making new ones enables the use of fewer resources without negative environmental impacts.

Recycling is, by comparison, the processing of discarded materials into new products, such as using crushed glass to make new containers, or melting scrap plastic to manufacture park benches. Although recycling does not represent as great an economic benefit as source reduction, and carries some environmental risk, it is seen as a viable means for reducing the amount of waste that must be landfilled or incinerated at any one time. In most cases, the recycling of waste materials into new products conserves raw materials, uses less energy and water than virgin materials, and presents less of an environmental concern than those waste management options lower on the hierarchy. (York, 1990) Some materials that currently have recycling markets within the United States include paper products, glass, metals, construction materials, and some types of plastics.

Composting is usually included as a subcategory of recycling, and involves the managed decomposition of discarded organic material, primarily for use as a soil amendment. (Martin, 1993) Materials that are commonly considered to be compostable include yard and landscape waste, food waste, animal waste and paper products. Composting operations can range from backyard "compost piles" composed of leaves and grass clippings to large indoor facilities with rotating drums to aerate a complex mix of organic materials.

A less desirable option in the waste management hierarchy is incineration. Also referred to as combustion, it is the controlled burning of waste materials either as a method of reducing the volume of waste and/or to generate energy. It can also help destroy pathogens and some toxic chemicals found in the waste stream. (York, 1990) Although some materials generate energy through the combustion process, the majority of waste materials save more energy through the recycling process than is given up during combustion. (Young, 1994) The ash generated, moreover, must then be disposed of in dedicated landfills. The fly ash, in particular, is of concern because of the concentrated accumulation of heavy metals and dioxins that attach to ash particles, materials that are considered by many to be toxic to humans.

Landfills, once no more than open pits, have improved dramatically in the last twenty years. Referred to as sanitary landfills, modern land-based disposal systems are designed to reduce the interaction of discarded materials with the surrounding land, water, and air. Some of the devices that are utilized to prevent this interaction include leachate collection systems, plastic and composite liners and covers, and in some cases, methane collection systems. Although landfill facilities are much more carefully constructed and maintained than in the past, they represent a net loss in the resources available for future manufacturing. In addition, the potential for environmental contamination remains. Sanitary landfills have become, in the United States, the preferred option for final disposal of waste products as the past alternatives of land and ocean dumping have been curtailed. (Alexander, 1993)

The Environmental Protection Agency (EPA) uses the term “integrated waste management” to represent the application of the waste hierarchy to local and regional situations, with the understanding that the different waste management options will be represented in varying proportions depending on the characteristics and conditions of the region. The goals for waste reduction set by the EPA do not specify which options are to be used; the term “waste reduction” encompasses source reduction, as well as reuse of materials, recycling, composting, and by some definitions, combustion. Many states have set volume goals as well, with waste reduction often measured as a reduction in the amount of waste entering landfills, or landfills and incinerators, regardless of the processes involved. (Fishbein, 1992)

Municipal Waste Reduction

Within municipalities, waste reduction and recycling programs have found favor as an alternative to increasing solid waste disposal costs. Coupled with a rising population in many areas, the amount of trash being discarded continues to go up: compared to 1960 estimates of approximately 2.5 pounds per person per day (Wagner, 1995), the

Environmental Protection Agency estimated an average of 4.4 pounds per person per day in 1993. (EPA, 1994) This figure includes discards from households as well as commercial and institutional sectors, but does not include manufacturing, construction, agricultural and mining wastes. (Alexander, 1993) An annual survey of state programs by the environmental journal Biocycle, which includes industrial waste disposed of in municipal facilities, places this figure even higher, at an average of 6.5 pounds per person per day for the same year. (Steuteville, 1995)

As the volume of solid waste increases, the number of operating landfills continues to decrease, as does the number of operating combustion and waste-to-energy facilities. (Decision-Maker's Guide, 1989) Although the national capacity for land disposal of municipal waste remains steady, the trend is toward larger, but fewer, sanitary landfills. (Rathje, 1992) As regional landfills close because of exceeded capacity or environmental concerns, increasingly restrictive legislation and opposition by community groups have prevented the opening of new sites in many areas. (Fessenden, 1989) This has resulted in increasing collection and disposal fees for many communities, making recycling and waste reduction a more attractive alternative financially, particularly in the urban areas of the Northeast and Northwest.

Siting of new landfill facilities, if it happens at all, can take years and run into the millions of dollars. (Bachman, 1995) Part of the reason for this is more restrictive legislation regarding the siting and operation of new facilities. The other part is the NIMBY, or "Not in My Backyard," syndrome that manifests within communities regarding the potential siting of a new landfill or combustion facility. There are several reasons for this opposition, one of them being concern for the environment and human health. There is also a “lack of public trust” toward both the operators and the regulators of landfill and combustion facilities. Community residents that live near a proposed landfill facility are concerned about property values and do not want to accept risk they see as involuntary and beyond their control, especially if the waste is generated outside the community. (Williams, 1990)

The NIMBY syndrome that has blocked the construction of new landfill and combustion facilities does not seem to be present to the same extent with regard to the siting of recycling and composting facilities. (Blumberg, 1989) From 1988 to 1990, Biocycle estimated growth in the number of materials recovery facilities (“MRF’s”) in the United States from 16 to 92, and composting facilities from 651 to 1407. (Steuteville, 1992) By 1994, the same source estimated the number of MRF’s in the United States at 1243, and composting facilities at 3202. A MRF in this instance is defined as a facility that sorts, bales and markets recyclables, although this varies somewhat from state to state. (Steuteville, 1995)

The growth in recycling and composting facilities serves as one informal measure of increasing municipal support for waste reduction programs. Another way to measure support for these programs is to look at the diversion rates reported by municipalities. Waste diversion refers to materials diverted for recycling and composting compared to previous discard totals. (Martin, 1993) In 1990, some municipalities were achieving diversion rates of greater than forty percent of their solid waste streams, primarily on the East Coast where landfill costs are high. (Platt, 1991) Nationwide, at least fifteen states reported municipal solid waste diversion rates of twenty-five percent or more of their waste streams for 1994. (Steuteville, 1995)

Industrial Waste Reduction Programs

The industrial sector has also embraced waste reduction and recycling measures, primarily for the benefits of cost avoidance, although human health concerns play a part as well. Because industrial processes often include hazardous materials, reduction in the quantity or toxicity of materials used can mean lower liability and cleanup costs for manufacturing companies in addition to lower disposal fees. (OTA, 1989) Generally, industrial waste reduction efforts fall into four categories: 1) modifying a technology, process or piece of machinery, 2) product redesign, 3) use of alternate input (raw) materials, and 4) improving the handling, storage or inventory of materials within an operational framework. (Rappaport, 1993)

Using waste reduction strategies has paid off for many companies, both monetarily and in terms of public image. (Makower, 1994) In 1985, 3M's highly publicized Pollution Prevention Pays program was credited with $300 million in cost savings and a 50 % reduction in wastes over the first ten years of the program. (Oldenburg, 1987) Current estimates of cost savings from the program are close to $600 million. (Makower, 1994) Dow Corning and Ciba-Geigy reported similar levels of cost savings following the introduction of waste reduction efforts, combining process improvements, materials management and by-product exchange programs in an effort to reduce the amount and toxicity of their waste streams. (Huisingh, 1982) Apple Computers' decision to use a recycled content corrugated material for shipping instead of bleached, virgin material has saved the company over $3 million since 1991. (Saunders, 1993)

The Role of Universities

Universities have a significant role to play in recycling and waste reduction efforts, both in their capacity as research institutions and because of the types of waste streams found on large campuses that could enable universities to implement effective waste reduction programs. (Hegberg, 1992) Instead of leading the way, however, many universities are lagging behind the municipal and industrial sectors in recycling and source reduction efforts. (Abbott, 1992) In 1991, a survey of campus recycling programs found that of those colleges and universities that had programs, about half were run by students on a volunteer basis, without the necessary support of campus administrators. Nearly seventy-eight percent of the roughly 3,500 colleges and universities in the country reported having recycling programs by 1993, although the type of program and estimated diversion of materials varies widely. (DeBell, 1994) Ithaca College in New York, for example, has an extensive paper products, metals, glass, plastics, oils, landscape waste and food waste recycling program. (Schoonover, 1994) Typically, however, colleges and universities have limited programs, collecting office paper or corrugated cardboard from academic buildings or residence halls.

Like their municipal counterparts, those universities that have committed to comprehensive recycling programs have experienced significant reductions in disposal costs. During 1994, the University of Illinois recycled 455 tons of materials, with a net savings of $67, 000.[1] (Hoss, 1996) Officials at Miami University, a school of 16,000 in Oxford, Ohio, determined that the total cost for a materials recovery facility to process materials from a diverse recycling program was one-third less than the cost of landfill disposal of those items, and provided an on-site learning opportunity for students. (Gaski, 1993) Cost estimates for recycling at The University of Colorado were about half of the cost of waste disposal. (RRS, 1991)

Waste Characterization Methodologies

For any sector of the economy to implement effective waste reduction measures, it is important to first identify the quantity and composition of the waste stream in question. (Tchobanoglous, 1993) Waste characterization can provide figures for planning collection programs, estimating total potential diversion from the waste stream, and identifying materials that should be targeted for waste reduction or recycling. This process can be accomplished in a variety of ways, depending on the sector in question.

For municipal waste streams, the Environmental Protection Agency publishes a periodic report, derived from production information for materials by weight, as well as information derived from end products found in the waste stream. This materials flow methodology is used to provide national average figures for municipal waste streams, and is thought to provide a more complete picture than could be obtained from other methods of waste characterization. Physical samples can be subject to regional differences, such as

[1] Net savings is defined as the disposal cost avoidance - the total recycling cost.

climate, socio-economic status, industrial or agricultural specializations and state governmental regulations, all of which may affect the composition of the waste stream . (Environmental Protection Agency, 1994)

Franklin, Associates, in conjunction with the Environmental Protection Agency, has used figures from the United States Department of Commerce as well as trade association data to provide information about materials and products. Allowances are made for manufacturing losses, exports and imports, and materials that are destroyed or diverted during use. Adjustments are also made for combustion activity, which are not included in totals. Organic products, such as food and landscape wastes, are estimated from widespread sampling procedures. In total, the figures published include residential, commercial, and institutional wastes. Some of the materials that are not included using this methodology include demolition and construction wastes, incinerator ash, and remnants of products left in containers. (EPA,1994) Although the majority of the figures using this method are calculated without physically sampling the waste stream, other studies of municipal solid waste streams, as well as Franklin's own confirming samples, are fairly close to these numbers. A study done in Brevard County, Florida concluded:

> "...the sum of the subcategories from Franklin and those obtained locally, ... do not vary widely. Since no major differences were observed it was concluded that the Franklin subcategories of the percentages of materials in the United States municipal solid waste streams could be utilized to estimate those same components in the state of Florida with reasonable accuracy."
> (EPA, 1990, p. 100)

Another form of this method is materials mass balance analysis. This method works best for determining the total amount of solid waste generated, by identifying all activities that generate solid waste within a given boundary and then using that information to mathematically derive the rate of accumulation. It is not as useful for determining the composition of the waste stream. (Tchobanoglous, 1993)

There is also a small, but significant, body of literature on the composition of materials found in municipal landfills and how these materials translate into information regarding consumer decision-making. Excavation of landfills to examine the types and amounts of waste can be helpful for targeting materials (like excess packaging or disposable diapers) for which alternate purchasing decisions could be made. (Rathje, 1989) The figures derived from these excavations are compatible with the Franklin materials flow percentages. (Alexander, 1993)

There is a developing body of literature on waste audits and life cycle analyses, primarily for use within the industrial sector. Both processes are designed to identify materials used during the process of manufacture in an effort to reduce or replace materials that are considered hazardous to human health and the environment. (Sullivan, 1995) RCRA refers to this endeavor as waste minimization, a term which embraces both source reduction and recycling of solid and liquid wastes in an effort to reduce the amount of hazardous material that must be disposed of in landfills or through incineration. (Oldenburg, 1987)

Life Cycle Analysis (LCA) is a process used to track the materials used in the manufacturing process, usually for a single product, in an effort to identify the potential tradeoffs involved in design, material or production changes. Opportunities for environmentally positive changes in the manufacturing process can be identified.

Conversely, the process can be used to analyze proposed changes that would, in the long run, only trade one type of pollution for another. In order to consider all possible effects, an attempt is made to examine all of the stages of a product's life cycle, from the collection of raw materials to its eventual disposal. The steps of a life cycle analysis usually include goal definition (purpose of the study), inventory analysis (quantifying the inputs and outputs of the manufacturing process), impact assessment (looking at the qualitative or quantitative impacts of those inputs/outputs), and improvement analysis (identifying areas that could be changed, with an end goal of environmental improvement). Life cycle analyses are recognized as a positive step for characterizing industrial waste streams, although the methodology for this process is still being developed. (Sullivan, 1995)

Characterizing University Waste Streams

Unfortunately, none of these methods for identifying waste stream characteristics is best suited for university campuses. The estimates of waste stream composition calculated by the Environmental Protection Agency and other organizations for municipal solid waste using materials flow methods are good starting points, but are not specific to university waste streams, which may differ significantly in content from those of municipalities. (Creighton, 1993) Municipal landfill excavations can be very helpful in making decisions about consumer habits, but have the limitation of not providing purchasing information for specific segments of the population, like college students. (Delin, 1992)

Except in very limited capacities, universities also do not resemble industry, as there is seldom an identifiable operational "process" for making physical products that can be targeted and identified. Nor are waste materials generally considered hazardous, with the exception of materials from laboratories and research centers located on university campuses. Industrial waste characterization approaches could be useful for this segment of the university waste stream, although hazardous materials usually represent a relatively small percentage of the total solid waste generated and may be disposed of differently from the majority of the solid waste stream.

Some of the unique characteristics of university waste not commonly encountered in municipal or industrial settings include: predictable seasonal fluctuations of activities and on-campus populations, concentrated densities of same-age residents, intertwined research, academic and athletic/event facilities, as well as (in some cases) large amounts of landscape or agricultural waste. As most campuses do not have available facilities for handling solid waste on site, waste management decisions must take into account municipal relationships or constraints regarding contracts with available waste management contractors. (Giannone, 1995)

In addition, there are mechanisms within the typical university structure for fairly effective distribution of information related to recycling and reduction education programs. A large body of students is available, many of whom possess levels of environmental concern often greater than those of the general population. (Watson, 1990) Many university campuses have school-year populations larger than municipalities with successful recycling programs, (Folz, 1990) indicating the potential for sustainable levels of materials recovery.

Some of the differences that exist between university campuses can affect the generalizability of waste stream characterization. Climate, size of the campus (particularly the extent of on-campus housing facilities), its mission toward "commuting" or part-time students versus full-time students, the types of programs and degrees that are offered, and state or local legislation are some of the variables that can affect the characteristics of the waste stream at any given university. (Friedman, 1993) From a study comparing the waste generation rates for seventeen colleges and universities, smaller colleges had larger per person rates of waste generation than larger ones, and universities with on-campus student housing had significantly greater rates of waste generation than colleges serving primarily a commuting population. (Hegberg, 1992)

These differences notwithstanding, the types of activities and populations found on university campuses make comparisons possible and provide direction for recycling and waste reduction programs. The use of a manual sorting approach combined with information on current levels of waste disposal and diversion can provide more accurate information about a specific university, as well as increasing the waste characterization information available for other universities making program decisions. The manual sorting approach to waste characterization entails physically dividing representative samples of the solid waste stream into categories and using the resulting measurements to estimate the percentage weight and volume for each category within the solid waste stream. Choice of categories to be examined vary, but are usually based on components of the waste stream that are potentially recoverable through recycling, composting or reuse. (Alexander, 1992) This provides a "snapshot" of the waste stream, and can pinpoint the areas upon which waste reduction and recycling programs should focus.

Although the standard deviations of previous studies utilizing this method of waste characterization have varied by as much as twenty-five percent, (Gay, 1993) careful planning and division of the campus into like strata can reduce this variability considerably. If the goal of the waste characterization is to project future diversion capacity, for those universities considering the implementation of a transfer station or materials recovery facility, repeated characterizations during the time it takes to develop and fund such a facility can provide specific numbers to supplement other projection methods. (Alter, 1991)

Waste reduction efforts can provide benefits both economically and for the environment. To develop effective waste reduction programs, however, it is necessary to have a clear picture of the types and amounts of materials found in the solid waste stream. Although there are a variety of methods for estimating this information, a well-planned manual sorting protocol analyzing representative samples of the waste stream in question can provide information of the necessary precision to predict potential capture rates or to evaluate current diversion programs.

It is hoped this study will provide information about the effectiveness of using a manual sorting design to evaluate the solid waste stream found within a university setting. The study is also designed to highlight the differences between estimates for municipal waste stream composition and the composition of university waste streams, using

Michigan State University as an example. Adding to the available information on solid waste characterization, this study should serve as a basis for comparison for those institutions conducting similar studies. It should also prove helpful as a rough estimate of composition for those institutions unable to conduct a waste characterization themselves.

Problem Statement

The purpose of this research is to find answers to two questions: 1) "How reliable is waste characterization, using a manual sorting design, in the evaluation of current and potential levels of recycling and waste reduction activities for university populations?" and 2) "In what ways do university solid waste streams differ from those of municipalities?"

Universities should be leading the way in the effort to meet state and federal waste reduction guidelines. The first step toward developing effective recycling and waste reduction programs is to establish a clear picture of the types and quantities of materials present in the waste stream. Although there are good estimates for the components of the solid waste stream available for municipalities, these estimates are not representative of university waste streams, and do not provide a usable model for integrated waste management planning for this segment of the population. Similarly, waste characterization models for the industrial sector, although very effective in reducing the amount of waste generated on an industry-by-industry basis, do not provide a usable model for integrated waste management for universities.

Objectives of the Study

The objectives of this study are to:

1. evaluate the effectiveness of a manual sorting model for characterizing the solid waste streams within a university setting.

2. quantify weights of specific materials being diverted from the waste stream via current Michigan State University recycling programs and estimate potential diversion rates for commonly recycled materials, for the purpose of complying with state and federal goals for waste reduction.

3. identify significant differences in composition between Michigan State University's solid waste stream and current United States municipal solid waste streams.

Hypotheses

There are two hypotheses that will be examined within this study. They are:

1. H_0: Using a manual sorting model with fewer than thirty samples, the percentages by weight of major components (greater than five percent) of a university solid waste stream cannot be estimated with an eighty percent confidence level and a $\pm$ two percent error from the mean.

H_1: Using a manual sorting model with fewer than thirty samples, the percentages by weight of major components (greater than five percent) of a university solid waste stream can be estimated with an eighty percent confidence level and a $\pm$ two percent error from the mean.

2. H_0: The percentages of major components of a university solid waste stream do not differ significantly from the estimated percentages of major components of municipal solid waste streams, at a ninety percent confidence level.

   H_1: The percentages of major components of a university solid waste stream do differ significantly from the estimated percentages of major components of municipal solid waste streams, at a ninety percent confidence level.

In the second hypothesis, "major components" refers to the categories used by the Environmental Protection Agency in Characterization of Municipal Solid Waste in the United States: 1994 Update: paper, glass, metals, plastics, wood products, food waste, and landscape waste/yard trimmings.

CHAPTER TWO:

REVIEW OF LITERATURE

Goals of Waste Characterization

Waste characterization can be defined as "any program which involves a logical and systematic approach to obtaining and analyzing data on one or more solid waste streams or substreams." (p. 2, MDNR, 1986) Waste characterization studies can serve a variety of functions, depending on the purpose and structure of the study. In general, the goal of waste characterization is to "identify the sources, characteristics and quantities" of the waste stream. (Powell, 1993) For the purpose of meeting state and federal guidelines, as well as planning effective waste management programs, a more specific set of goals would be to: 1) identify materials that should be targeted for reduction and recycling programs, and 2) evaluate the success of any current programs in removing materials from the waste stream. Individual waste characterizations can also contribute to the general body of knowledge, both to assist others in the field (EPA, 1989) and to highlight changes in composition due to legislation, technology, or changing attitudes. (Clarke, 1992)

Identifying the kinds of materials to be targeted for waste reduction and recycling programs should be based on several criteria. First, those materials contributing a significantly large percentage (greater than 5%) of the waste stream, either by weight or volume, should be examined for possible inclusion in recycling or waste reduction programs. (Gay, 1993) Although weight is the most commonly used material measurement, the capacities of collection vehicles make volume a consideration as well.

measurement, the capacities of collection vehicles make volume a consideration as well. (Tchobanoglous, 1993) In the case of cardboard, for example, the weight of the material might not be considered significant, but the volume could make a large difference in truck capacity and the necessary number of "runs" a collection vehicle would need to make.

The second criteria is related to markets; are there industries within a reasonable distance willing to take or buy the material? If there is no local market for it, there is the potential of needing to stockpile the material until a large enough amount is amassed to interest a more distant buyer, or of combining materials with a nearby municipality. (Solid Waste Management Task Force, 1989)

The third consideration concerns the mechanics of collection. Is the material relatively easy to collect? Is there capacity within the collection system to accommodate additional pickup without capital outlay for new equipment? Any potential purchase of additional capital equipment needs to be measured against estimated cost savings of diverting the material from the landfill and the attendant tipping fees. (Sound Resource Management, 1993)

In geographic areas with high transportation costs or landfill tipping fees, recycling programs can divert a significant amount of materials, and provide a reduction in waste disposal costs. Recycling programs in areas with low or moderate landfill tipping fees are usually not money-making propositions, due to market fluctuations and the difficulty of competition with subsidized virgin materials. The costs of collecting and processing the recyclables may outweigh the cost of landfill disposal. Although sale of the collected materials may offset any additional expense, the market for recyclables remains somewhat unpredictable, making it difficult to rely on this as a source of revenue. (Apotheker, 1995) For a community or institution, using a waste characterization to determine the criteria as listed above can reduce the costs of operating a recovery program and ensure that the most economical materials are chosen to meet waste reduction goals. (Jablonowski, 1995)

Performing a waste characterization is also a positive way to measure the success of current programs that may already be in place. Comparing the types and amounts of materials found in the waste stream characterization with known amounts from recovery programs can give a good estimate of the proportion of material diverted from the waste stream during the time period of the study. The necessity of compliance with state recycling and reduction goals can make this an important consideration, especially for public institutions, although there are private colleges and universities that are complying with these goals as well. (Creighton, 1993)

State and Federal Waste Reduction Guidelines

The Resource Conservation and Recovery Act of 1976 asked that individual states "establish and justify priorities and timing" (p. 44) for the development of integrated solid waste management plans. This includes source reduction, which is defined as any practice that reduces the toxicity, volume, or weight of materials in the waste stream prior to disposal or diversion. Source reduction does not technically include recycling, which is the recovery of post-consumer and production discards for use as raw materials in manufacturing, or direct reuse of materials through exchanges or salvage programs.

(Curbing Waste, 1990) For the purposes of this study, the term "waste reduction" is understood to encompass any practice that reduces the amount of materials being landfilled or incinerated, including source reduction, reuse or recycling.

The U.S. Environmental Protection Agency has set goals of diverting twenty-five percent of the nation's solid waste through recycling and source reduction programs by 1992. (U.S. Environmental Protection Agency, 1990) It hopes to raise that to thirty percent by the year 2000. (U.S. Environmental Protection Agency, 1994) Municipal waste streams seem able, so far, to met these guidelines: one estimate put the national 1994 MSW, or municipal solid waste, recovery rate at twenty-three percent for 1994, up from nineteen percent in 1993. (Steuteville, 1995)

State goals vary widely, with states setting specific percentages that range from twenty-one percent by the year 2000 for the state of Delaware to seventy percent at an unnamed future date for the state of Rhode Island. (Steuteville, 1995) Most state programs do not refer specifically to universities and colleges, but a few require these institutions to develop specific integrated waste management plans that meet the state goals for waste reduction.

In Illinois, for example, the 1990 adoption of PA86-1363 included a section known as the "College Recycling Law," specifically targeted toward two and four year public colleges and universities. It requires a 10 year comprehensive waste reduction plan and a 40% reduction in solid waste disposal by the year 2000. (Hegberg, 1992) The state of Tennessee enacted The Solid Waste Management Act of 1991, requiring that all public colleges and universities develop waste management plans focusing on recycling and source reduction. (Powell, 1993)

Michigan currently does not have specific legislation focused on universities, but has set statewide recycling goals to reduce solid waste disposal fifty percent by the year 2005. (Steuteville, 1995) Some public universities within the state show indications of moving toward that goal: The University of Michigan reports a waste diversion rate of twenty-three percent, Central Michigan University twenty-five percent, and Western Michigan University twenty-seven percent. Michigan State University, by comparison, reports diversion rates of thirteen percent; an indication of a significant gap between current waste diversion program totals and state goals, as well as the efforts of other Michigan universities. (Michigan State University Recycling Coalition, 1995)

Using Waste Characterization to Meet State and Federal Guidelines

As previously stated, waste characterization studies can be instrumental in targeting materials for waste diversion programs as well as estimating the effectiveness of recovery programs already in place. In municipal recycling programs, this can be referred to as "participation rates," or the number of households participating in recycling programs compared to the total number served by the program. Another way to measure this is to use the "diversion rate," a more inclusive term that includes all material diverted from the waste stream, compared to all material diverted plus all material discarded. (Riley, 1993) This second method is more easily calculated at the university level and can be derived from waste characterization methodologies like manual sorting along with data collected by diversion programs operating within the university.

After deciding the purpose of the waste characterization, planning the study itself entails making decisions about the structure and analysis. Some of the important factors to consider prior to initiating a manual sorting procedure include sampling design and the procedures for choosing the samples, the organization of the sorting process itself to reduce possible bias, and the waste streams and categories of materials that should be examined.

Recommended Sampling and Evaluation Techniques

The EPA's recommendations for solid waste characterization sampling , although primarily concerned with hazardous materials, has applicability for any type of solid waste. The recommendation for designing a sampling plan is that representative samples be used, or samples "exhibiting average properties of the whole waste." This can mean using simple random techniques, stratified random techniques (for use when differences are observed in the waste stream either spatially or over time), and systematic or authoritative random sampling, which is planned to focus on or avoid known anomalies in the waste stream being studied. Related to this, there is the specification that "enough samples be collected over a period of time sufficient to represent the variability of the waste." (p. 9-6) The Environmental Protection Agency also recommends an eighty percent confidence level when evaluating the representativeness of the sample. (Environmental Protection Agency, 1986) accuracy and precision requirements of the intended data uses. At the same time, it needs to maximize the data output for a given budget." (p. 10) A 200-300 pound sample is recommended, with the number of samples varying depending on the type of waste stream and the component being measured. Results should be stated in terms of means and standard deviation. (MDNR, 1986)

Another source states that a sample size of approximately 200 pounds varies insignificantly from larger sample sizes for municipal waste, if taken from a truckload of representative waste material. As most truckloads are much larger than this, the load should be quartered repeatedly until a sample of the appropriate size is reached. This source suggests that results be considered in terms of mean, standard deviation from the norm and the variation coefficient to determine how representative the chosen samples are of the waste stream being examined. (Tchobanoglous, 1977)

The University of Illinois Center for Solid Waste Management and Research procedure for conducting a manual sort (adapted from a method developed for municipal solid waste by the American Society for Testing and Materials) recommends a 200-300 pound section taken per vehicle load of MSW. The samples should be collected during a period of at least one week, with the suggestion that at least twenty and preferably thirty samples be taken to ensure a normal distribution. The exact number of samples necessary should be estimated from the expected mean and the statistical confidence level and precision desired. (Hegberg, 1992)

Martin, in an analysis of manual sorting protocols for municipal waste streams, found that forty samples, each weighing two hundred pounds, would yield a two percent error at an eighty percent level of confidence. For the same level of error, estimated sample numbers of sixty-three were suggested to reach a ninety percent level of confidence, with ninety samples necessary to reach a ninety-five percent confidence level. It was also noted that material categories found in smaller percentage categories tended to have a relatively larger amount of error on a proportionate basis than those materials composing a larger percentage of the waste stream. Basing the number of samples on the larger components of the waste stream provided the opportunity to further reduce the number of samples needed to twenty to provide a two percent error at an eighty percent confidence level. (Martin, 1993)

Other examples of sampling protocols can be drawn from the municipal sector. A field study undertaken by the Ventura County Solid Waste Management Department used a total of 307 samples to characterize the municipal solid waste stream for five jurisdictions. These samples were characterized by residential, commercial, and industrial populations, and sorted into six general categories of materials. Residential samples were taken from individual home garbage cans set out for collection, using random address selection. Larger samples from the commercial and industrial stratas were divided into grids from which random samples were selected. The resulting data was examined for a sample mean in pounds per person per day as well as the percent of total and standard deviation for each material group. The confidence level used was ninety percent. The total tons disposed and diversion rates by material type were estimated as well. Results were also examined by jurisdiction, with significant differences in waste characteristics and amounts found to exist between jurisdictions. (Delin, 1992)

Elias Musa, conducting a study to determine optimum sample size for municipal waste characterization, used a systematic sampling procedure, a variation of random sampling that is useful in field work. His method for this was to sample one household out of each twenty-five, following the routing of standard collection vehicles. His recommendation for the number of samples needed was based on the projected volume of materials in the waste stream: for items thought to compose large percentages, sample numbers of thirty to forty were recommended for a ninety-five percent confidence level. For items thought to be less common, Musa recommended at least two hundred samples to obtain the same degree of accuracy. (Musa, 1981)

Sampling protocols can also be evaluated qualitatively. John H. Martin listed the following criteria used to evaluate waste assessment protocols: 1) The protocol should require the minimum time necessary to attain the desired confidence level, 2) the resulting data should be accurate, reliable and valid, 3) consideration should be made of the pattern in which trucks bring discards to the landfill, 4) the people involved in the sorting process should be able to understand the protocol with less than four hours training, and 5) there should be minimal disruption of landfill operations. (1993)

Each of these studies provided insight on the sampling techniques commonly used in the field of waste characterization. Although there is not a firm consensus in this area, an eighty percent level of confidence can be determined to provide an acceptable basis for evaluation of sample integrity. To reach this level of precision, at least for major material categories, at least twenty and preferably thirty samples are necessary as a minimum.

Choosing Categories of Materials

There are wide variations among waste characterization studies regarding choice of materials categories. Most often, categories are chosen based on the intended waste management strategies. For instance, a study to determine the potential amount of materials available for a waste-to-energy facility would choose different categories than a study evaluating the success of current recycling programs. For combustion, categories would be grouped by their Btu, or British thermal unit, potential. Papers and wood products would be of greater interest than metals and glass. (NREL, 1992) For the purpose of developing or evaluating a recycling program, the solid waste stream would be evaluated for those materials currently or potentially recyclable, like paper, metals, glass and plastic. Different paper products would need to be evaluated separately, as the market price for each varies. (OTA, 1990) Composting operations would be interested in what is often called the "putrescibles" component of the solid waste stream: items that decay fairly quickly like food, yard waste, and other organic materials. (Martin, 1993) Planning for waste reduction would necessitate examining manufactured materials that could be purchased in a reusable format instead of disposable as well as materials for which a lower-use alternative could be substituted. Some examples are computer printer cartridges, disposable cups and plates, batteries and light bulbs. (Curbing Waste, 1990) Program planning that combines these waste management options would need to plan materials categories with a compromise between ease of sorting and desired information about composition. Larger numbers of categories increase sorting time and may reduce precision for categories constituting very small percentages of the waste stream. At the same time, too few categories may not provide the desired information about the waste stream.

Manual Sorting Considerations

The methods used for physically sorting solid waste materials vary considerably, based on study objectives, personnel available, physical facilities, and budgetary constraints. Some of the primary considerations include staffing, safety equipment, sorting equipment and sorting site. Not surprisingly, finding individuals willing to manually sort solid waste is a difficulty common to this form of waste characterization. The issue of safety for the sorting personnel is important to prevent injuries from sharp items or contaminated waste products. The choice of a sorting site and sorting equipment can be essential to maintaining sample integrity.

The Michigan Department of Natural Resources recommends that manual sorting studies be conducted at a landfill facility with three to five workers and a knowledgeable supervisor. Personal safety equipment should consist of at least heavy boots, gloves, eye protection and a mask (respirator). Minimum sorting equipment includes a sorting table with a screen to separate fine material, sort containers, and a scale for weighing material, with a plastic sheet covering the sort site. (MDNR, 1986)

The Standard Handbook of Environmental Engineering (Corbitt, 1990) recommends the sorting be done indoors, with room for both equipment and collection vehicles depositing samples. Each of ten crew members should be assigned one material to collect (with a rolling barrel) from the sample located on the floor of the sort area.

When containers are full, they are to be wheeled to the weighing area and the crew member continues with an empty barrel. Oversized materials are segregated and photographed. After the pile of waste is reduced in size, it can be transferred to a sort table, with one-inch square screening. Crew members should be provided with long-sleeved coveralls, puncture resistant gloves, and heavy workboots. Unfortunately, an indoor facility with the necessary characteristics was not available for this study, so this protocol was not considered as a model.

The waste characterization study conducted at East Tennessee State University used student volunteers working in shifts, with 10-15 people working at any given time for the two days of the sort. The students were provided with Tyvek suits, eye protection and butyl gloves to prevent accidents, and signs were posted with safety rules. The samples were sorted on tables into plastic containers and weighed. The study was conducted outdoors on the campus near the physical plant. (Powell, 1993)

For the Tufts University (Medford Campus) waste sort, students were also the majority of the work force. They were provided or asked to bring gloves and some form of eye protection. The sort was also conducted on the campus, near the dumpster being sorted. The waste material was emptied from the dumpster onto the ground and taken by students to specified nearby sites labeled with the chosen categories of materials. The sorted materials were then placed in clear plastic bags and weighed. (Creighton, 1993)

All of these campus protocols were instructive when planning this waste characterization study. After considering the study objectives and available facilities, it was determined that the protocol outlined by the Department of Natural Resources was the best starting point for planning the protocol for the manual sorting of the samples.

University Waste Characterization Methodologies

A waste stream assessment plan for East Tennessee State University divided the waste stream into nine strata and manually sorted one sample from each strata into thirteen categories of materials. Samples consisted of an individual dumpster from each strata and ranged in weight from 345 to 1,252 pounds. The samples were chosen using a variation on random sampling referred to by the Environmental Protection Agency as "authoritative sampling": the samples were identified by knowledgeable parties as most representative of the stratum. (Environmental Protection Agency, 1986) Total weights for the campus were determined by weighing selected dumpsters periodically and extrapolating total weight for the academic year. Using one-way and two-way ANOVA's, the sampling results were tested for any difference in means between the strata for the material categories selected. Significant differences between strata were not found in this case, and the author concluded that the number of samples was sufficiently representative of the campus waste stream. (Powell, 1993)

A study undertaken by Tufts University considered in part the different waste strata divisions present on college campuses. Tufts divided the waste streams into administrative buildings, dormitories and dining halls. For the purpose of a materials flow assessment, the campus was further divided into housing, offices, labs, dining services, athletic facilities, grounds, and other buildings. An assessment of the University of North

Carolina, cited in the Tufts study, used the division of administration buildings, academic departments, and residence halls. (Creighton, 1993) This study did conduct waste characterization sampling on a limited basis, but was primarily a comparison of other partial waste stream studies conducted on college campuses.

A compilation study of other university programs used the divisions of educational, administrative, residential and dedicated purpose areas like libraries and computer centers to differentiate the waste streams. The study also found significant differences in generation rates between colleges with significant on or near campus housing and those colleges that were serving primarily commuting students. Larger universities also were shown to have less per-person waste generation than smaller universities. This study found variability in the waste stream on a monthly basis, with larger amounts of materials present during the months considered to be part of the traditional school year. Existing recycling and composting programs were thought to influence waste stream composition as well. (Hegberg, 1992)

The studies of waste streams on college campuses vary in their choices of strata, making comparison difficult. Adopting the strata divisions used by the University of North Carolina should make possible some limited comparison and makes a useful structure for analyzing the differences between waste streams. These studies highlight some characteristics of college waste streams to be considered when designing a protocol.

Overall, as this review of the literature base on waste characterization demonstrates, there is not yet a high degree of consensus regarding the type of protocol to be used when conducting a manual waste characterization study. After a review of available information, as well as examining the characteristics and informational needs of the Michigan State University campus, it was decided that no one of the protocols described in this review was able to meet all of the study objectives. Therefore, the research approach is a compilation of strategies used in other waste characterization studies, modified for the chosen research site. It is hoped the resulting protocol will serve as a useful model for other universities planning waste characterization studies.

CHAPTER THREE:

DESCRIPTION OF STUDY METHOD

Description of the Research Site

The main campus of Michigan State University is situated on 1500 acres, and enrolled approximately 41,000 students at both the undergraduate and graduate levels for the 1994-1995 academic year. The residence hall system consists of twenty-five buildings with fourteen cafeterias which feed and house approximately 14, 500 students during the academic year (September to May). In addition, there are university apartments that house approximately 2200 students and their families (about 5400 adults and children) year round. Academic facilities on campus include a veterinary school, two medical schools, eight sports facilities, and forty-five academic and office buildings, twelve of which have laboratory or medical facilities. There are also several dedicated or special event facilities, including a performing arts center, a union with food service, a planetarium and a laundry. The large number of on-campus students as well as the large variety of buildings and academic programs provided a large, comprehensive waste stream from which to sample, and gave a greater probability that information derived from this study will be applicable to other programs.

The campus was divided into three strata for analysis: residence halls, university apartments and academic/administrative buildings, including athletic and dedicated facilities. The decision for this division was based on: 1) previous studies of university waste stream analysis, 2) a preliminary characterization conducted in the spring of 1994 with limited samples to establish the potential differences between strata, 3) the routing availability of the grounds department to provide dedicated samples for analysis and 4) the intention of using the results of the study to plan waste reduction programs specific to these areas of the campus. Agricultural buildings not on the main campus were excluded for two reasons: lack of access to collection routes for these buildings and lack of proper equipment to sort the waste stream from these facilities, which consists primarily of animal waste and bedding.

Material Categories

Examining the available literature regarding material categories for solid waste characterizations, it became apparent that there wasn't a general consensus on the types of categories that should be used. Therefore, the categories chosen were a combination of other suggested sorting classifications. They were chosen to provide information about several facets of the waste hierarchy, for the specific planning needs of the Office of Waste Reduction at Michigan State University. Some of the categories were chosen to provide information about recycling (paper, plastic, metal, and glass). Another category were chosen to provide information about compostable materials (organics, sometimes referred to as putrescibles), and the remaining categories were chosen to provide information about materials that could be reduced in amount or reused instead of being discarded (construction debris, textiles and manufactured goods). Within each of these eight categories were several subcategories, for a total of forty-eight material divisions. A complete list of categories and subcategories is given in Figure 3, found in the discussion of sorting procedure. The use of these categories was designed to provide information either by major category for comparison with other programs, or by subcategories, for a more precise focus on specific materials found within the waste stream.

Timing of Study

The first part of the waste characterization study was conducted during the last two weeks of July, 1994. The timing of the study was designed to provide a representative waste stream to sample, as this time period fell roughly in the middle of the summer semester. As other studies have shown, the beginning and end of the semester are not representative because students are moving into and out of the system. (Powell, 1993)

The second part of the study was scheduled for the last two weeks of October, again to avoid the unrepresentative nature of the beginning of the term as well as wet or snowy weather common to November and December. Unfortunately, the study was unable to avoid the wet weather. This, in addition to scheduling problems caused by students' class schedules, caused the fall segment of the waste characterization to be extended a third week in order to obtain enough samples.

Sampling Procedure

The Grounds Department at Michigan State University, which is responsible for the collection and hauling of campus solid waste, agreed to bring loads of solid waste from the university to a privately owned landfill in nearby Lansing during the time period collection and delivery of materials from only one strata at a time. For the summer study, samples were taken from each load picked up by the grounds department from the campus. Exceptions to this were loads in which more than one strata had been combined, special events waste was included, or adequate samples had been already been taken from that strata, in which case samples were not taken from that vehicle load. Special events waste in this case refers to an event called the Michigan Festival, which is a one-time influx of a population not primarily related to campus activities and not representative of the usual campus waste stream.

Almost all loads came to the landfill in thirty-eight cubic yard compactor trucks, most of which were considered to be full, and therefore compacted to the same degree. Because the residence halls do not house undergraduate students on a regular basis in the summer, resulting in a smaller and less consistent waste stream, this was the most difficult strata from which to collect full, compacted loads. Although one residence hall was in full-time operation (Owen Graduate Hall) and some residence halls were housing high school students for athletic camps and orientations, most of the loads from this strata were partial loads and therefore somewhat less compacted than those from the other two strata.

The front-loader trucks that brought the majority of the loads to the landfill ejected their loads in the form of a “loaf”, a roughly rectangular mound of refuse that measured approximately 30’ x 10’ x 8’. Each of these loads was then divided into twelve sections (6 for partially full loads) and 1-2 sections were randomly selected with the aid of a random number generator. These sections were then divided into 100-200 pound samples with the aid of landfill personnel and a small bulldozer that transferred the samples onto with the aid of landfill personnel and a small bulldozer that transferred the samples onto tarps at the sorting site. An effort was made to ensure the samples included material from both the top and bottom of the section to reduce the potential for bias from weight-related shifting of materials. The samples that had been placed on tarps near the sorting area were then covered to reduce moisture gain from precipitation and loss from evaporation until they could be sorted. A diagram of this sectioning procedure is given in Figure 1.

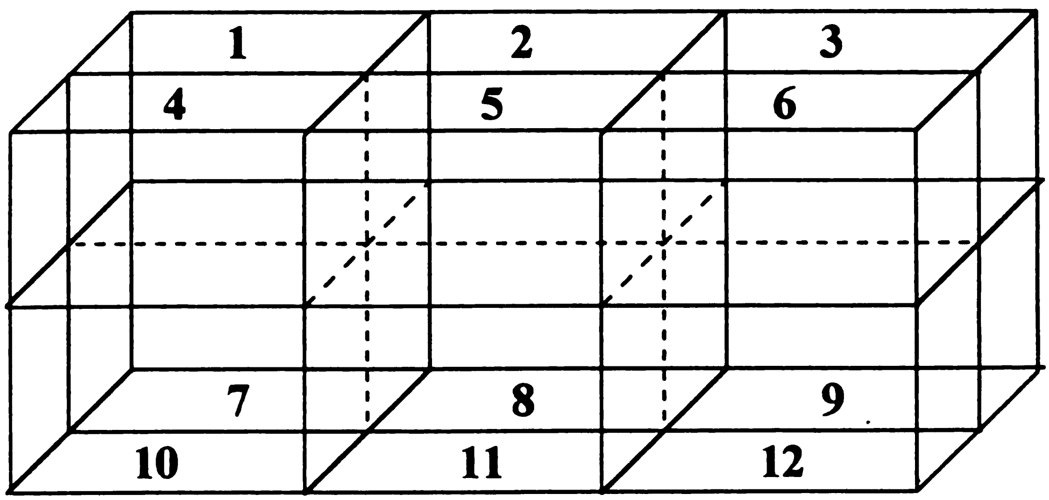

Figure 1. Sectioning Procedure for Sample Selection

Manual Sorting Protocol

The sorting area was located in the landfill near the working face, with a 1-2 foot pad of sand covering the landfill floor. A large tent was erected, both for storage of equipment and as shelter for potential bad weather. It also served as a place to store student protective gear and other belongings. The actual sorting was conducted primarily outside the tent, unless there was rainy weather. The weighing area was located just inside the door of the tent. A battery operated digital floor scale with increments to one-tenth of a pound was used for weighing of materials. A diagram of the sorting site is given in Figure 2.

Plastic containers of three different sizes were used for sorting and weighing materials. The size container chosen for each subcategory was based on the expected volume of each material. A color-coded label in a plastic sleeve was attached to each container, with all materials within the same category given the same color label. This helped both in the daily set up procedure and to avoid confusion during sorting and weighing. Material containers from the same category were grouped together near the sort table with one person nominally responsible for each major category. The containers were weighed prior to the sorting process and labeled with tare weights. They were also weighed periodically during the sorting process to avoid the possibility of inaccurate measurement due to occasional buildup of debris or sand. The approximate organization of material containers and the size containers used is indicated in Figure 3.

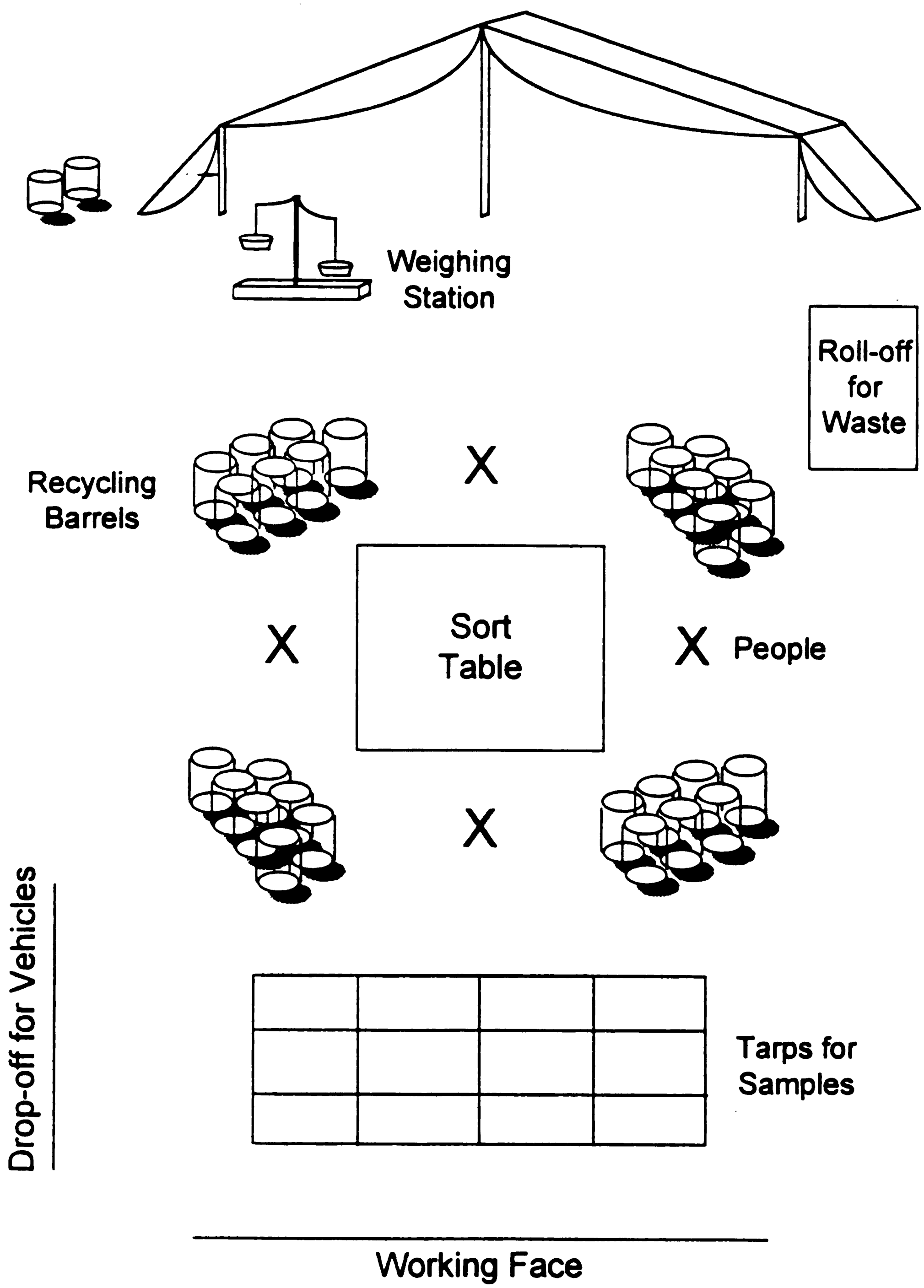

Figure 2. Diagram of Sorting Site

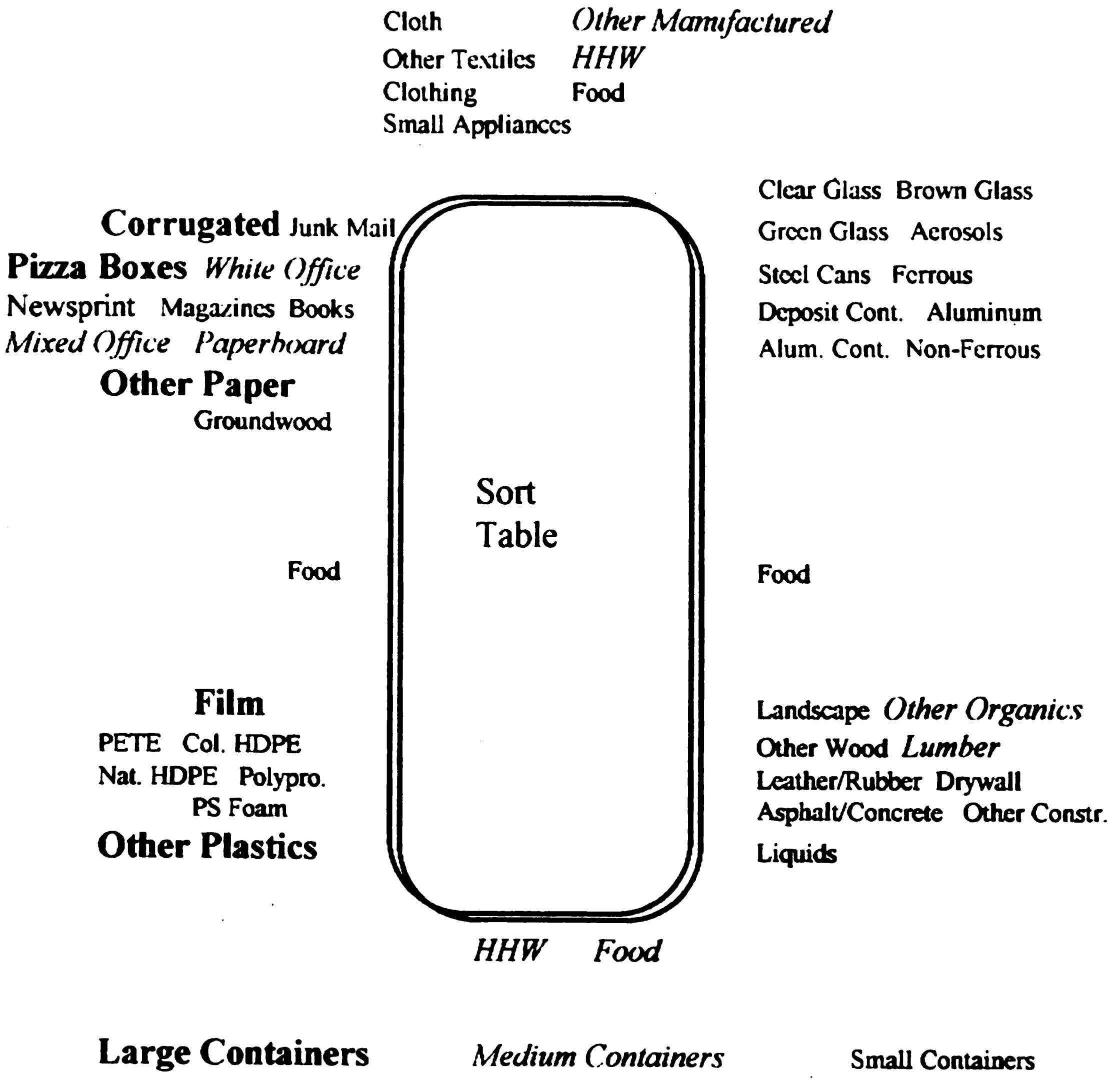

Figure 3. Material Categories by Container Size and Arrangement for Sorting

The samples were sorted manually by a team of four or five student employees. Very large items that did not fit into the containers were removed from the samples first and weighed separately. The remainder of the sample was placed on the sort table and sorted into the categories listed in Figure 3. A sort table with one inch wire grids was used, which enabled materials smaller than one inch to fall through the grid. The preliminary study conducted in the spring of 1994 showed a significantly greater amount of sorting time necessary for each sample when materials smaller than one inch were included in the sorting procedure, without a significant increase in the sample weight of individual materials. This material was weighed separately and added to load totals as a sub-category of organic materials called residuals. Some of the materials typical for this category included soil, sawdust, fragments of glass and plastic, small paper and foil wrappers, and food crumbs.

After the samples were sorted into plastic containers, they were taken to the weighing area where the weight, container tare and approximate volume were recorded on the worksheet shown in Appendix A, and then either emptied into a rolloff container for disposal or a large plastic container for recycling. The information recorded on the worksheets was then transferred to the database program EXCEL for analysis.[2] Initially, a portable computer was on site for this purpose, but the lack of a power supply and the threat posed by blowing sand and dust made this impractical.

With roughly the same group of students for the duration of the two week summer study, the time necessary to sort a sample and prepare for the next one averaged approximately thirty to forty minutes, depending on the size of the sample. The number of

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[2] copyright Microsoft Corporation

persons involved in weighing and estimating volume was kept to a minimum to reduce recording bias, with the researcher weighing and recording the majority of sample weight information.

Safety equipment for personnel included Tyvek coveralls, heavy shoes or boots, hats, eye protection, and paper respirator masks. Two pairs of gloves were used, one of woven stainless steel or Kevlar to resist penetration by sharp objects and an outer glove of polypropylene to repel moisture. A two-hour training was scheduled to communicate safety issues, sort procedures and material categories.

For the fall waste characterization, a similar method was used, with three variations. The residence halls were in the process of installing compaction systems, which meant some of the loads from this strata were delivered by the grounds department in ten or fifteen cubic yard compacting dumpsters. The same random selection process was used, but modified for the smaller volume of the dumpsters, and fewer samples were taken from these loads. The increased amounts of waste material for the fall semester, (compared to summer) necessitated samples be taken for each strata from approximately every fourth truck that picked up dedicated (individual strata) loads on the campus, using a routing schedule worked out with the grounds department. This schedule, given in Appendix B, was based on established pickup routes, vehicle availability, and the sampling needs of the study.

Fall semester classes and less flexible schedules for the students sorting materials meant that it was not possible to use the same five students for the three week sampling period. Approximately twenty-five students were scheduled in two four hour shifts each weekday, with most students working two or more shifts per week. A sample schedule is given in Appendix C. An attempt was made to compensate for the larger number of sorters by using the students who had participated in the summer study as "shift supervisors," with at least one of these students present for each four hour shift. In addition, the director of the Office of Recycling and Waste Reduction and the researcher were on site most of the time. Students were involved in a three hour training session on safety procedures and categories of materials. An outline of the training session and informational materials given to student employees involved in the fall sort is provided in Appendix D. In addition to the training on correct sorting procedures, material containers were examined briefly before weighing by the shift supervisor to remove any incorrectly sorted material. Sample sorting times averaged fifty to sixty minutes, and the average number of samples sorted per day was six. This was partially due to scheduling difficulties and the students being less familiar with the sorting process, and partially due to poor weather conditions on several of the sort days. Photographs of the sorting procedure are detailed in Figures 4 and 5.

Figure 4. Transferring a Sample to the Sort Table

Figure 5. Student Employees Sorting a Sample

The first priority for analyzing the data from the waste characterization study was to establish the representativeness of the samples to the waste streams from which they were taken. In other words, the samples within each strata were compared to their respective means to find the level of potential error. The samples from academic/administrative buildings, residence halls and university apartments were aggregated separately to determine the sample mean percentage for each major category (those categories comprising more than five percent of the waste stream by weight) as well as the standard error from the mean within an eighty percent level of confidence for both the summer and fall sorting periods. The eighty percent confidence level was chosen because of the wide variation common to this form of waste characterization, (Gay, 1993) and the understanding that the purpose of the data in this case was to provide an estimate of the major components of the waste stream.

A second measure of the effectiveness of this sampling protocol was to examine the ease of use and the reproducibility of the method used. For this, Martin's criteria for waste assessment protocols was used as a guideline. These criteria included considerations like the training of employees, routing of collection vehicles, and the reliability of the data collected.

To evaluate the second objective, the sample mean percentages for each of the campus waste streams were then aggregated with information from current campus landfill diversion programs and compared to the percentages of materials estimated by the Environmental Protection Agency for municipal waste streams using multiple student t-tests at a ninety percent level of confidence. Student t-tests highlight significant differences between sample means and the population mean, in this case represented by the EPA/Franklin model. This provides an indication of significant differences in the relative amounts of materials found in the solid waste streams of municipalities compared to those found within a university setting, and determines whether the second hypothesis should be accepted.

For the first objective of the study, the student t-tests were used to identify which categories of materials differ significantly between municipal and university waste streams. This, then, becomes the basis for examination of the individual strata to identify which materials should be targeted for potential diversion from the waste stream to meet state waste reduction goals.

To meet the second and third objectives, estimates of the total weights of major materials (as defined in the first hypothesis) for the year were calculated using the percentages from the waste characterization and the reported total weight of all general refuse materials collected by the grounds department for each strata. For the purposes of the study, fall characterization percentages were used to calculate total material weights for both fall and spring semesters, making the assumption that the spring waste stream (and campus population) was similar to that analyzed in the fall. Information for the months of May, June, July and August was used to calculate summer diversion, and the remaining months were considered to be part of the fall and spring semesters.

Weights of materials diverted from the waste stream were derived from records kept by those programs currently in operation at the university. These included an office paper and newspaper recycling program run by the Office of Recycling and Waste Reduction, a cafeteria recycling program in one of the residence halls (Brody Complex), a corrugated cardboard recycling program undertaken by the Grounds Department, and student run materials recovery programs in several other residence halls. These figures were aggregated and used to estimate: 1) total yearly percentage of materials (1994-95) diverted from the campus waste stream, excluding agricultural and special events waste 2) percentage of each major category (paper, metals, organics) currently being diverted from the waste stream and 3) estimated weight of commonly recyclable materials that could potentially be diverted from the waste stream on a yearly basis.

Limitations and Key Assumptions

Collection and Sorting of Samples

There are some limitations to this type of study. As other studies of this type have found, there is some uncertainty with the scheduling of samples and data collection, which means the sampling method cannot be completely random. (Tchobanoglous, 1977) Pickup schedules planned with the grounds department are still subject to the vagaries of unforeseen situations that may necessitate last-minute schedule changes and missed samples. The Grounds Department was not able to designate a separate truck for this purpose, which would have allowed for a more rigorous random sampling method. It is hoped that the adherence to random sampling technique within loads and the large number of samples from each strata would somewhat compensate for this limitation. Because the sorting was conducted outside in an open landfill, precipitation on several days limited the number of samples that could be sorted on a given day, interfering with the scheduled numbers of samples to be sorted as well as potentially increasing measured material weights, especially for paper products. An effort was made to limit this bias by covering samples, sorting under shelter if the weather was wet or by calling off sorting for any day for which there was too much precipitation.

A further limitation is volume calculation of materials. Because of the variation in structure and compressibility for different materials, the estimations were assumed to be somewhat inaccurate. For this reason, attention has been given primarily to data based on weight, as is customary for this type of study. The main purpose of the volume data was to provide an estimate for calculating equipment needs, and therefore is not included in this analysis.

A third limitation was the safety concern involved with sorting some samples. Because of concerns for the safety of the students sorting materials, samples found to contain excessive amounts of hazardous materials (such as unlabeled chemicals, animal waste, or torn biohazard bags) or large amounts of broken glass or other sharps from laboratories were discarded without being sampled. These types of samples constituted approximately ten percent (5 samples) of the total samples taken from the academic/administrative stratum (no samples of this type were found within the residence hall or university apartments strata), and therefore the figures for this category may be closer to six percent than the five percent figure given.

Data Assumptions

When analyzing the results of the data collections, some assumptions were made due to limitations of time and budgets. One was the lack of samples specific to the spring semester. Although it was not possible to collect extensive samples for the spring semester, it is assumed for this study that they would be similar to the data collected during the fall semester for the following reasons: 1) a much smaller preliminary study was conducted during the spring of 1994 showing results similar to those found in the fall of 1994, 2) for municipal solid waste, one of the biggest variations between Fall and Spring waste streams is related to yard waste, which at MSU is composted or left on lawns and is therefore not a significant part of the waste stream, 3) other activities on campus, as well as student population, remain fairly consistent with the exception of moving out procedures at the end of the spring term. It was not feasible to conduct separate characterizations of waste generated at the beginning and end of the semesters, and it should be noted that reporting by residence hall managers indicated that this strata may differ somewhat at these times, with increased amounts of corrugated cardboard at the beginning of the fall semester and increased amounts of textiles, paper, manufactured goods and wood waste from lofts at the end of the spring semester. However, much of this material is currently being diverted by residence hall managers for reuse. (Drake, 1992)

Regulatory and Structural Limitations

Each state varies somewhat in its legislation related to waste reduction. This can have an effect on the composition of the waste streams within the state in question. Likewise, each university can be assumed to have different types of structures in place that might affect the results of a waste characterization study. The regulatory and structural limitations mentioned here were in place prior to 1990 and are not included in an analysis of the total waste stream. They may, however, impact a comparison between Michigan State University and other universities and should be taken into account in that event.

The State of Michigan passed a mandatory beverage container deposit law in 1976. This provided for a ten cent deposit for all plastic (PET), glass and aluminum containers used for carbonated beverages. It is difficult to predict the extent to which this may have influenced the amounts of those materials found in the waste stream, but it is likely that much less of these materials would be present than in states without beverage container deposit legislation. Although there are no numbers available specific to the Michigan State University campus, the average return rate for these containers within the State of Michigan is estimated to exceed ninety percent. (Pasterz, 1996)

Michigan State University, like many land grant universities, has extensive open land in and around the main campus. The majority of landscape waste from the campus has been composted or otherwise reused by the grounds department for more than five years, and is therefore not included in the figures presented here. It can be assumed that percentages for landscape waste for universities without this type of program would be higher.

The university has also operated a salvage facility since early in the twentieth century. Used manufactured goods belonging to the university are sent to the facility for resale to the general public or donation to service organizations. This includes items ranging from furniture and appliances to computers and other electronic equipment. Although this policy is not always followed, the salvage facility diverts a sizable percentage of manufactured items that may have influenced the amount of materials from that category found during the waste assessment.

CHAPTER FOUR:

DATA ANALYSIS

Review of Sampling Protocol

Because there is no one accepted protocol for conducting manual waste characterizations, the design of the sampling protocol contains components of accepted research methodologies, as well as components that are unique to this study. The design of the study will be reviewed briefly prior to examining the objectives of the study.

Material Categories

Eight major groupings of materials were used, with subcategories for each, for a total of 48 sort categories. The categories chosen were a composite of other suggested category groupings, and were chosen for the specific informational needs of the campus Office of Recycling and Waste Reduction. The large number of categories served two purposes: to give a more complete picture of the waste stream as an information base for future recycling and waste reduction efforts as well as to provide the opportunity for combining categories in a flexible manner for comparison with other waste assessment data. A list of the categories and subcategories is given in Table 1.

Sample Selection

Samples were taken from truck loads that had picked up waste materials from one of three building types on campus: residence halls, university apartments, and academic or administrative buildings. Both of the sorting periods were scheduled for the approximate middle of the semester, to avoid the anomalous waste streams found during the

Table 1. Categories of Materials for Waste Characterization

1) Paper	2) Plastics	3) Glass
White Office	Films	Clear Container
Mixed Office	Clear PET, #1	Green Container
Magazines/Glossy	Natural HDPE, #2	Brown Container
Corrugated	Colored HDPE, #2	Other Glass
Pizza Boxes	Polystyrene Foam	
Paperboard	Other Plastics	
Bound Groundwood		
Books		
Newsprint		
Junk Mail		
Other Paper		
4) Metals	**5) Organics**	**6) Construction**
Alum. Cans/Foil	Food	Asphalt/Concrete
Other Aluminum	Landscape Waste	Drywall
Steel Cans	Wood Waste	Lumber
Ferrous	Leather/Rubber	Other CD
Non-Ferrous	Residuals	
Aerosol Cans	Liquids	
	Other Organics	
7) Textiles	**8) Manufactured/Other**	
Cloth	Small Appliances	
Carpeting	Clothing	
Other	Furniture	
	Packaged Goods	
	HHW/Medicines	
	Deposit Containers	

the beginning and the end of an academic term. During the two week long summer semester waste characterization, samples were taken from every truck load that fit this description. During the three week long fall waste characterization, samples were taken from every fourth truckload, because of the increased volume of solid waste generated during the school year. One or two of twelve sections was taken from each of these loads using a random number system, and divided into approximately 200 pound sorting samples.

Sorting Procedure

The samples were sorted one at a time on a sort table with one inch mesh into the 48 subcategories detailed above. Four to five students were involved sorting the samples into three differently sized plastic containers that were marked with the material name and tare weights. The samples were then weighed by material and the weights recorded on a worksheet for later input into an EXCEL spreadsheet. Using EXCEL, each sample was converted to percentage figures, dividing each material category by the total weight of the sample taken. This allowed for comparison between samples without regard to the variation in weight of individual samples.

A total of 160 samples were taken from the campus waste stream, with a combined weight of 28,000 pounds (14 tons). Although an effort was made to select samples with a weight of approximately 200 pounds, the average weight of the samples was somewhat less than this. A breakdown of the number of samples taken from each strata and their average weight is given in Table 2.

Table 2. Breakdown of Sample Characteristics by Strata and Semester

	Academic/ Administrative		**University Apartments**		**Residence Halls**	
	Sum	Fall	Sum	Fall	Sum	Fall
Number of samples taken	22	23	25	25	40	27
Average weight of samples (in pounds)	164	134	181	171	198	178
Weight variation among samples (in pounds)	80-319	79-199	117-290	97-323	91-375	80-285
Estimated weight of waste stream during time of study (in tons)	775	1550	451	901	1090	2181
Estimated percentage of the waste stream being sampled (for 2 week time period)	1.8%	1.4%	4.3%	3.3%	3.1%	1.5%

Evaluating the Effectiveness of A Manual Sorting Model

The first objective of the study was to examine the effectiveness of using a manual sorting model for characterizing the solid waste stream within a university setting. As Table 2 illustrates, the number of samples taken for each segment of the waste stream was less than 30, with the exception of the residence hall strata during the summer semester. This is a smaller number of samples than is generally recommended for this type of waste characterization. The contention of this study is that this is an adequate number of samples to characterize the Michigan State University waste stream, when it is divided into strata with similar characteristics. In this case, that means that the summer semester waste stream should be considered separately from the academic school year waste stream, and that dividing the campus into residence hall (RH), university apartments

(UA), and academic/administrative buildings (AA) will improve the precision of a manual waste characterization.

The method used to establish the representativeness of the samples entailed first identifying those categories that made up the majority of the waste stream, by strata and semester. Major components are defined as those materials that compose five percent or more of the waste stream by weight. Within each strata, the samples were then compared to their respective mean percentages to find the level of potential error. Using the software program EXCEL, the standard error from the mean at an eighty percent confidence level was calculated for each component by strata and semester. These figures are given in Table 3.

To evaluate the effectiveness of this model from the data presented in Table 3, it is necessary to examine the first hypothesis of the study, which states:

H_0: Using a manual sorting model with fewer than thirty samples, the percentages by weight of major components of a university solid waste stream cannot be estimated within an eighty percent confidence level and a $\pm$ two percent error from the mean.

H_1: Using a manual sorting model with fewer than thirty samples, the percentages by weight can be estimated with an eighty percent confidence level and a $\pm$ two percent error from the mean.

The results of these calculations show it is possible in most cases to estimate the mean percentages of major components of each waste stream within an eighty percent confidence level and a two percent error, using this methodology. Given these results, the null hypothesis should be rejected. For those components that had a greater than two percent error, further comments are made in Chapter Five. For the sake of comparison, the same procedure was used to calculate the standard error from the mean for the major

Table 3. Percentage Means and Percent Standard Error of Major Components of the Michigan State University Waste Stream by Semester and Strata

Strata	Material Category	Percentage of the Waste Stream	Standard % Error from Mean
AA-Summer (n = 20)	1. White/Mixed OP	8.6	1.0
	2. Corrugated	10.9	1.5
	3. Newsprint	5.6	0.87
	4. Other Paper	14.8	1.5
	5. other organics	7.4	2.3
	6. HHW	6.1	1.7
AA-Fall (n = 23)	1. white/mixed OP	6.7	0.63
	2. corrugated	9.6	1.4
	3. newsprint	15.8	2.8
	4. other paper	12.4	1.4
UA-Summer (n = 25)	1. other paper	9.2	0.75
	2. food	29.5	1.9
	3. HHW	7.7	0.9
UA-Fall (n = 25)	1. corrugated	5.3	1.1
	2. newsprint	6.8	1.2
	3. other paper	11.2	1.5
	4. plastic film	5.1	0.49
	5. food	25	2.3
	6. HHW	7.6	1.1
RH-Summer (n = 27)	1. corrugated	7.7	0.76
	2. other paper	10.2	1.1
	3. plastic film	6.2	0.56
	4. food	23.5	2.8
	5. construction	5.5	1.2
RH-Fall (n = 40)	1. corrugated	8.2	1.1
	2. newsprint	9.2	1.4
	3. other paper	16	1.3
	4. plastic film	7.2	0.8
	5. food	16.8	1.7

components of the waste stream as a whole, using the entire population of 160 samples. The results are given in Table 4.

Table 4. Percentage Means and Standard Error from the Mean for Major Components of the Michigan State University Waste Stream

Material Category	Percentage of the Waste Stream	Standard % Error From Mean
1. Corrugated	18.4	0.46
2. Newsprint (ONP)	7.4	0.64
3. Other Paper	12.1	0.55
4. Food	18.4	1.16
n = 160		

Estimates of Current Diversions from the Waste Stream by Strata

The second objective of this study was to quantify the weights of specific materials being diverted from the waste stream through current Michigan State University recycling programs, and then use these figures and the information from the waste characterization to estimate the potential diversion rates for commonly recycled materials, for the purpose of complying with state and federal goals for waste reduction.

This was accomplished by first identifying those programs on the campus that divert materials from each of the three stratas used in the study. The types and amounts of materials diverted was estimated from records kept by those programs involved in recycling efforts on the Michigan State University Campus. This includes the Office of Recycling and Waste Reduction, the Grounds Department, and a residence hall recycling program run by undergraduate students. Because some estimates were made by months, the months of September through April were considered to be part of the Fall/Spring semesters, and the months May through August were considered to be part of the summer semester. Although the final calculation for potential diversion is given as an academic year total, the current diversion amount by program is separated into Fall/Spring semesters and Summer semester because some programs were not in operation during the summer. Diversions being made from the solid waste stream at Michigan State University at the time of this study are described below according to strata.

A drop-off program run by the Office of Recycling and Waste Reduction collected a total of 38.1 tons of recyclable material from the university apartments during the 1994-95 academic year. This constituted 2.7% of the university apartments waste stream. A breakdown of amounts by weights and materials is given in Table 5.

Table 5. Waste Stream Diversion from University Apartments, 1994-95

Material	Summer Amounts (tons)	Fall/Spring Amounts (tons)
1. Papers (cardboard, office paper, newspaper, magazines)	7.7	16.2
2. Container glass	1.6	4.8
3. Plastics (clear/colored HDPE, clear PET)	1.4	2.7
4. Metals (tin/steel, aluminum)	0.96	2.6

A paper pick-up program run by the Office of Recycling and Waste Reduction collected 805.7 tons of materials from academic and administrative buildings for the 1994-95 academic year. This constituted 25.7% of the academic and administrative solid waste stream for this time period. A breakdown of materials and amounts is given in Table 6.

Table 6. Waste Stream Diversion from Academic and Administrative Buildings, 1994-95

Material	Summer Amounts (tons)	Fall/Spring Amounts (tons)
Paper (white/mixed office paper, newspaper, magazines and other)	270.7	535

Four programs were in operation during the 1994-95 academic year to collect residence hall materials. One was a volunteer program run by undergraduate students in some of the residence halls for door-to-door collection from residents. The second was a cafeteria-based collection program run by cafeteria and residence hall personnel. The third was a corrugated cardboard collection program run by the Michigan State University Grounds Department for part of the year. There was also a limited program through the Office of Recycling and Waste Reduction, estimated at five percent of program totals. The combined weight of these programs is 254.6 tons, which constitutes 7.2% of the residence hall waste stream. A breakdown of these figures is given in Table 7.

Table 7. Waste Stream Diversion from Residence Halls, 1994-95

Material	Summer Amounts (tons)	Fall/Spring Amounts (tons)
1. Paper (white/mixed office paper, newspaper,corrugated cardboard,magazines and other)	50	197
2. Metals (aluminum, tin/steel)	0.5	3
3. Container glass	N/A	2.7
4. Plastic (clear/colored PET, clear/ colored HDPE, Styrofoam)	0.1	1.3

Overall, 1098.4 tons of materials were diverted from the university waste stream by all of the recycling programs combined. With a total estimated waste generation rate of 8046.4 tons for the year, (including waste disposed and waste diverted) the overall recycling/diversion rate for the university was estimated to be 13.6 %.

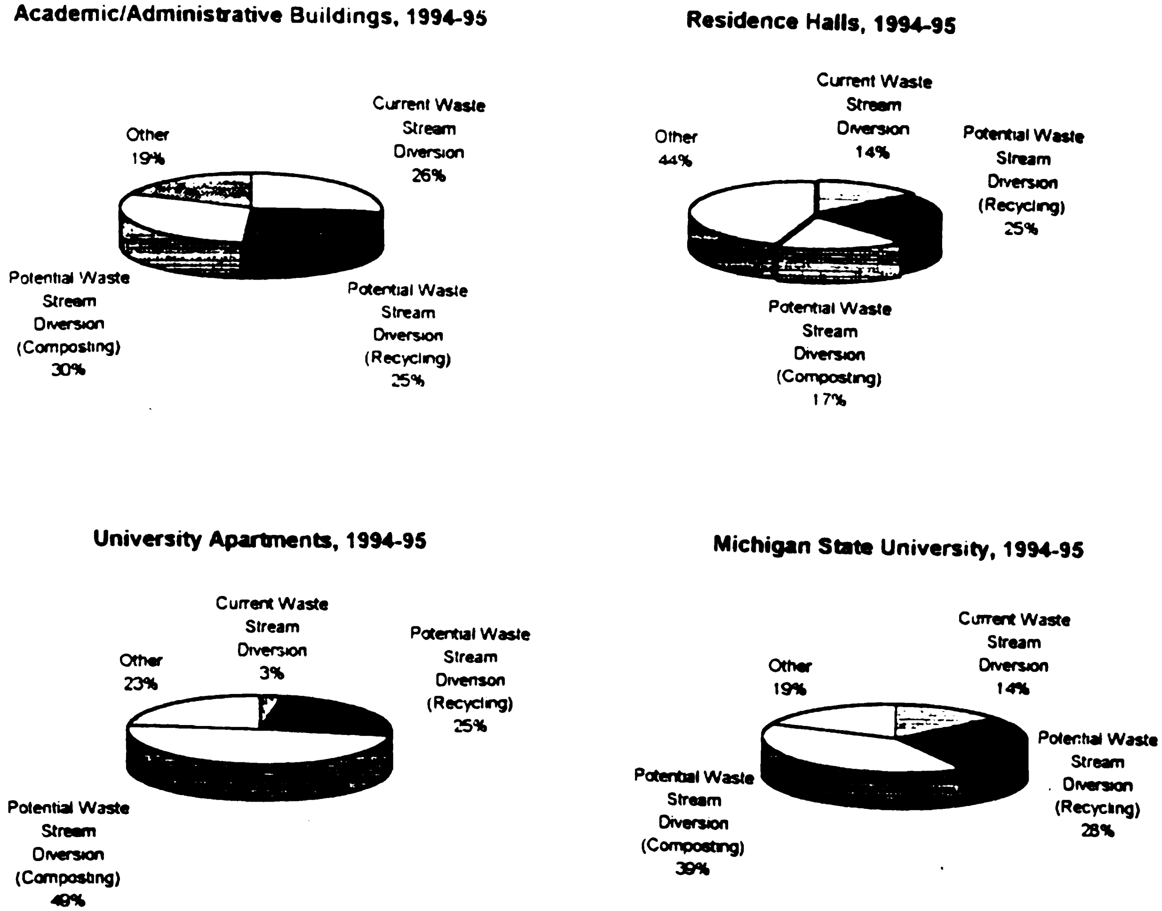
Potential for Additional University Waste Stream Diversion

The goal of the second research objective was to estimate potential diversion rates for the University, using the figures estimated above and the composition information derived from the waste characterization. Potential diversion rates were calculated using the percentages derived from the waste sort for commonly recycled materials, including: white and mixed office paper, newspaper, magazines, corrugated cardboard, metal containers and foil, HDPE (#2) and PET (#1) plastic containers, and glass containers. The percentage amounts by weight for these material categories derived from the waste sort were multiplied against the total estimated weight of the waste stream for each strata. Using the resulting figures from this, estimates for the current and potential diversion amounts by weight for the 1994-95 academic year are given in Table 8. A graphic representation is given in Figure 6.

Table 8. Estimates of Current and Potential Diversion from the Michigan State University Waste Stream by Strata

	Current Diversion Amounts (tons)	Additional Potential for Diversion (tons)	Current and Potential Diversion Percentage Amounts By Strata
Academic/ Administrative	805.7	797	51%
University Apartments	38	344.8	27.5%
Residence Halls	254.6	1096	38.3%

Overall, assuming the distribution of materials discarded on the campus remains the same, there is the potential for diverting approximately 2,238 additional tons of material per year, for an overall recycling rate of 41.4 % of the solid waste stream. This is much greater than is currently being realized on the campus. Implementation of more comprehensive recycling programs, even without additional source reduction or composting programs, would put the University much closer to the diversion rates being realized at other state universities and well on the way to reaching future state recycling goals of 50% waste reduction by the year 2005.



Current Waste Stream Diversion: Current programs in operation, including office paper, corrugated, newsprint, magazines, #1 and #2 plastics, and metal/glass containers
Potential Waste Stream Diversion (Recycling): Same materials as listed above, but with a more comprehensive collection system
Potential Waste Stream Diversion (Composting): Including the diversion of food and other organic materials

Figure 6. Estimate of Current and Potential Diversion From the Michigan State University Waste Stream, By Strata

Comparison with 1994 EPA/Franklin Estimates for Municipal Waste Streams

The third objective of the study was to identify significant differences between Michigan State University's solid waste stream and current United States municipal solid waste stream estimates. The EPA/Franklin model was chosen as the best indicator of the composition of municipal solid waste streams, with the estimates used here taken from the 1994 report of 1993 waste stream data. There were three major calculations used to complete a comparison between the percentage composition of the MSU solid waste stream and the EPA/Franklin estimates for municipal waste streams.

The first step was to group the subcategories used in the university waste stream characterization using the category divisions from the EPA/Franklin model. In most cases, divisions were similar. An illustration of how those subcategories were grouped is given in Table 9. The mean percentages for subcategories were added to obtain percentages for divisions in those cases where more than one subcategory was incorporated.

Table 9. Incorporating the Michigan State University Waste Characterization Categories Into the Category Divisions of the EPA/Franklin Model for Municipal Waste Streams

EPA category: paper and paperboard	EPA category: metal
MSU category: all paper subcategories	MSU category: all metal subcategories
EPA category: plastics	EPA category: food
MSU category: all plastics	MSU subcategory: food
EPA category: glass	EPA category: wood
MSU category: all glass	MSU subcategories: lumber, wood
EPA category: yard trimmings	EPA category: other
MSU subcategory: landscape waste	MSU categories: organics (except food
	and wood waste), construction debris
	(except lumber), textiles, and manufactured

The second step was to aggregate the mean percentages for all samples, regardless of strata and semester, to determine the overall mean percentage for each of the EPA categories. These figures were then used to estimate the weight in tons for each category for the academic year 1994-95. This was done so that the weights of materials diverted from the waste stream could be added back in for the purpose of this comparison, as the figures given in the EPA/Franklin model are prior to waste diversion (recycling) programs. After these figures were added to the total, the weight in tons was recalculated as percentage figures using the computer program EXCEL.

The hypothesis for determining significance is given as:

H_0: The percentage of major categories of a university solid waste stream do not differ significantly from the estimated percentages of major categories of municipal waste streams, at a ninety percent confidence level.

H_1: The percentages of major categories of a university solid waste stream do differ significantly form the estimated percentages of major categories of municipal solid waste streams, at a ninety percent confidence level.

Using these aggregated mean percentages as representative of the University's total waste stream prior to diversion for recycling, a student t-test was used to test for significant differences between the two waste streams at a ninety percent confidence interval for each of the major categories. The formula used is:

$$t = \frac{(X - \mu)}{s / n} \qquad | \, t \, | \geq t\,\alpha/2$$

where X = mean sample value for a given strata and material
μ = population mean as calculated by EPA   n = number of samples
s = standard deviation of the sample mean
t $\alpha/2$ = 1.711 with 24 degrees of freedom and a 90% confidence interval

Results of the t-tests for each category are given in Table 10. Using the definition for significance given in the hypothesis, the mean percentages for municipal waste streams are significantly different than those of the University, for every category except plastics. This indicates that the null hypothesis should be rejected in this case. A graphic comparison of the mean percentages for each material category is shown in Figure 7.

Table 10. Comparison of Michigan State University's Solid Waste Stream with EPA/Franklin Municipal Waste Stream Figures Using T-test

Material	University Mean %	Population Mean %	SD	T-value	Conclusion
paper	48.4	37.6	15.4	9	reject null (more than MSW)
plastic	8.7	9.3	5	1.5	do not reject null (similar to MSW)
glass	2.9	6.6	2.8	16.8	reject null (less than MSW)
metal	3.2	8.3	3.8	17	reject null (less than MSW)
food	15.9	6.7	14.6	7.9	reject null (more than MSW)
wood	1.1	6.6	2.4	28	reject null (less than MSW)
landscape	1.2	15.9	2.5	74	reject null (less than MSW)
other	18.2	9.0	2.5	46	reject null (more than MSW)
Using a t-value of 1.658, with n=162 and a two-tailed alpha of .05[2]					

[2] t value is taken from Statstical Concepts and Methods, Gouri K. Bhattacharyya and Richard A. Johnson, John Wiley and Sons: New York, 1977.

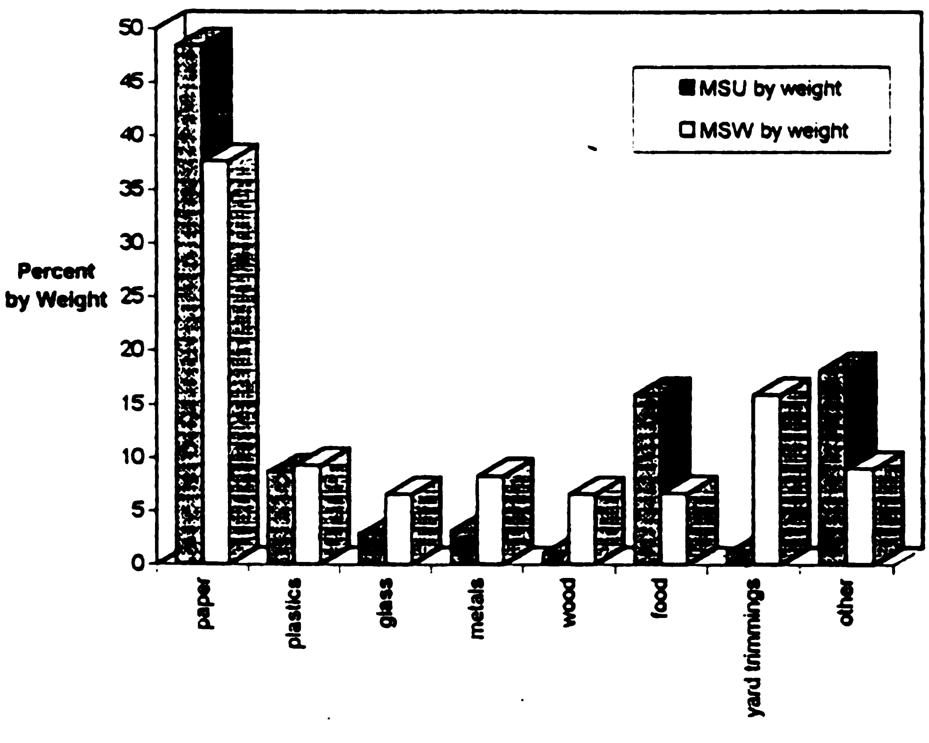


Figure 7. Comparison of Michigan State University's Solid Waste Stream with EPA/Franklin Municipal Solid Waste stream Estimates by Material Category Percentage of Total

A comparison of the EPA/Franklin municipal solid waste estimates was also done separately with each of the three university strata, using the same mathematical process. Results are given in Table 11. Out of the eight material divisions, significant differences in mean percentage amounts were found for almost all categories within each strata. This is an indication that Michigan Sate University's waste streams should be considered significantly different than municipal waste streams inmost respects, with appropriate modifications in the types of materials that should be targeted for diversion and reduction programs.

Table 11. Comparison of the Michigan State University Waste Stream with EPA/Franklin Municipal Waste Stream Figures by Strata Using T-test

Strata and semester	n=	Results
Academic/Administrative, summer	22	all materials significant
Academic/Administrative, fall	23	all materials significant except plastic
University Apartments, summer	25	all materials significant
University Apartments, fall	25	all materials significant except paper
Residence Halls, summer	40	all materials significant except paper
Residence Halls, fall	27	all materials significant
Using a t-value of 1.658, with a two-tailed alpha of .05.		

CHAPTER FIVE:

SUMMARY AND CONCLUSIONS

The costs of solid waste land disposal are rising. This is partially a result of concern about perceived environmental and public health risks, as well as legislative measures that limit where and how landfills can operate. To reduce concern about these potential risks and increase the effective use of available resources, alternatives to landfilling should be an integral part of any waste management plan.

Characterizing the waste stream is a necessary first step in the development of effective waste reduction programs, which include source reduction and reuse strategies as well as recycling and composting programs. It is the contention of this study that a manual sorting model is an effective method for characterizing university waste streams.

University waste streams present both unique challenges and unique opportunities for waste reduction. Some of the distinguishing characteristics of university waste streams that make them different than either municipal or industrial waste streams are: 1) the densely populated residence hall system, with large numbers of transient same-age students, 2) the academic scheduling found on a university campus, including semester arrivals and departures, and 3) the types of activities and functions that are common to universities. Because there is no one established protocol for conducting a manual waste characterization, these considerations had to be taken into account when designing this manual sorting model.

Because of the academic calendar, the sampling procedure was scheduled to take place during the middle of the semester to avoid the waste streams associated with activities at the beginning and the end of the semester. Sampling was scheduled for both the summer and the fall semesters of 1994, to determine if there were major differences between semesters in the composition of the waste stream. The campus waste stream was divided into three strata: residence halls, academic and administrative buildings, and university apartments. This division was based on the assumption that each segment of the campus waste stream would have distinct characteristics. The Grounds Department at MSU delivered truckloads from each of the three strata. Samples weighing approximately 100-200 pounds were taken using random sampling methods. The samples were sorted by student employees into 48 material categories chosen to provide a precise picture of the waste stream composition.

Evaluating the Effectiveness of the Manual Sorting Model in Predicting Major Components of the University Waste Stream

The first objective of this study was to evaluate the effectiveness of a manual sorting model for characterizing the waste stream within a university setting. The effectiveness of this manual sorting protocol was evaluated primarily by examining the information gathered for major components within each of the three stratas. Major components in this case refer to those materials found to comprise ≥ 5% of the waste stream by weight. The samples taken for each semester and strata were compared to their respective mean percentage values at an 80% level of confidence to evaluate if the mean percentage for major components could be predicted within a ± 2% error. Stated as a hypothesis,

H_0: Using a manual sorting model with fewer than thirty samples, the percentages by weight of major components (greater than 5 percent) of a university solid waste stream cannot be estimated with an eighty percent confidence level and a ± two percent error from the mean.

H_1: Using a manual sorting model with fewer than thirty samples, the percentages by weight of major components (greater than 5 percent) of a university solid waste stream can be estimated with an eighty percent confidence level and a ± two percent error from the mean.

For all but three materials, it was possible to predict the mean percentage by weight for each material within this 2% standard error. The null hypothesis was rejected in this case. This indicates that the manual sorting model used provides a highly acceptable means for identifying the major components of the solid waste stream within a university setting. Dividing the waste stream into three strata with similar characteristics reduced the number of samples needed to attain a usable precision for waste characterizations.

Those materials that were not accounted for within the two percent error include **food** (UA fall and RH summer) , **newsprint** (AA Fall) and **other organics** (AA summer). With the exception of **other organics**, these materials comprise a large (greater than fifteen percent) segment of their respective waste streams. The error for each of these categories was greater than two percent, but less than three percent. Possible explanations for these variations, based on researcher observation, include: 1) food waste in university apartments during the fall semester- the greater part of the population within this strata rely on university assistantships or state aid. Both of these income sources are received on a monthly basis, meaning that the timing of food purchase and consumption are probably influenced, with a greater consumption and discard rate immediately following disbursement and a lesser consumption for the remainder of the month; 2) food waste in residence halls during summer semester- there is no long-term population of students in the residence halls during the summer, with the exception of Owen graduate hall. The residence halls are not operating on a continuous basis, and some are not occupied at all. The intermittent operation of the residence hall cafeterias helps account for the great variability in food waste generation between samples during this time period; 3) newspaper waste in academic and administrative buildings during fall semester-there are three factors that may account for the higher variability of newspapers in the waste stream: weekly newspaper subscriptions by staff and faculty, the delivery schedule of the campus newspaper, and variability between buildings with staff participation in the campus recycling programs. Discarded newspapers are picked up by the Office of Recycling, but the participation among academic and administrative units is voluntary and variable. Observation during the waste sort indicated newspapers usually came in groups, probably daily discards of newspapers that were not read and were not placed in recycling containers; and 4) other organic waste from academic and administrative buildings during summer semester- this appears to be due to animal bedding and other materials that were only generated by certain buildings involved with animal research and care, causing a wide variation in sample amounts. Very little plant matter was noted, although soils were periodically found in the waste stream from this strata.

<u>Evaluating the Effectiveness of the Manual Sorting Protocol Used to Gather Sampling Data</u>

Although the quantitative measurement of this manual sorting model is the best indication of its effectiveness in predicting the components of the waste stream, effectiveness can also be evaluated in a qualitative manner. Martin's criteria for evaluating waste stream analysis protocols made a useful framework for evaluating the protocol used in this waste characterization.

The first criterion was that the protocol should require the minimum time necessary to attain the desired confidence level. To achieve the desired confidence level of 80% for this study, at least twenty samples needed to be taken from each strata during both the summer and fall semester sampling periods. To reach this goal of sixty samples, it was estimated that four sorters could sort eight samples per eight hour day. This estimate meant that eight days would be needed for the sorting procedure, with one day for setting up the site and one day for breaking it down. For the summer sort, this estimate was fairly accurate: as stated in Chapter Three, each sample took approximately 30-40 minutes to sort, with additional time needed for setting up the site in the morning and storing the materials at night. Because the site did not have cleanup facilities, additional time was needed for lunch-time cleanup and transportation. Fifteen minute breaks were observed every four hours. For the fall sort, it was estimated that additional time would be needed to sort the samples due to the relative inexperience of the student employees, as well as the additional time needed for transportation to and from the campus. This was indeed the case, with sample sort times increasing to an average of 50-60 minutes, with six samples sorted per day. Although more time was needed to sort the samples in the second instance, it is felt the accuracy of the results was not significantly affected, and that this type of schedule is more feasible for those waste sorts utilizing student assistance during the academic school year.

Martin's second criterion was that the resulting data be accurate, reliable, and valid. For the purposes of this study, a confidence level of eighty percent was adequate. In most cases, the data gathered using this protocol were accurate within a small amount of error at this confidence level. There is always a tradeoff between the number of samples gathered and the total cost of the study. In this case, the required precision was obtained while staying within desired cost parameters.

Two of Martin's criteria relate specifically to the assumption that manual sorting protocols are conducted at sanitary landfill facilities. The criterion that consideration should be given to the pattern in which trucks bring waste to the landfill was important to this study because of the need to examine each of the three strata separately. A schedule had been set up with the Grounds department prior to the beginning of the study, and frequent radio contact helped insure that the correct types of loads were being delivered for sampling. The criterion that landfill operations should be disrupted as little as possible was also taken into account in this study. Some of the ways the protocol tried to avoid disrupting the normal schedule include: sorting near the working face, agreeing to specific beginning and ending dates, keeping lines of communication open with landfill staff, and following all traffic and safety guidelines.

An important criterion for this or any protocol is the training of employees on waste sort procedures and safety considerations. This manual sorting model enabled employees to understand the protocol with less than four hours of training during both the summer and fall semesters. Training of sorters is essential to the collection of accurate data as well as the safety of individuals. Comparing the summer and fall sorting procedures, it is certainly desirable to have the same employees sorting all samples, but using students to sort samples means that this is not always possible. Four hour shifts were a feasible alternative, and there did not seem to be any difference in the accuracy of the resulting data. A very useful supplement to the training session was the supervision during the fall sort by those individuals already experienced in the sorting protocol.

Targeting Further Waste Reduction Efforts

The second objective of this study was "to provide the opportunity to identify those materials and stratas that would provide the best opportunity for further waste reduction efforts." Currently, the university is not meeting state and federal goals for waste reduction, and lags behind other public universities within the state regarding the amount of waste being diverted to recycling programs.

The first step in increasing the amount of waste being diverted to recycling programs is to identify those materials that should be considered for inclusion. As previously stated, the choice of targeted materials should be based primarily on three considerations. One consideration is the amount of material present in the waste stream; the more material that is available for diversion, the more successful will be the effect on the waste steam as a whole, and the more likely there will be a market for the materials that are diverted. Another consideration is ease of collection and transportation of materials. If materials are very bulky (large volume to weight ratio), requiring larger collection vehicles or more frequent collection, or present a hazard during storage or collection, there will be greater costs associated with them, making their diversion less attractive. Finally, there needs to be a market for the materials, making it easier to fund the collection programs and ensuring that diverted materials are used to complete the recycling process.

The material categories previously identified as having an established market value are: white and mixed office paper, newspaper, magazines, corrugated cardboard, metal containers and foil, HDPE and PET plastic containers, and glass containers. Of these, corrugated and newsprint compose ≥5% of the waste stream overall, and office paper composes ≥5% of the academic/administrative strata. These materials represent the potential to divert an additional 2800 tons of waste materials from the University's waste stream, with an overall potential recycling rate of over 40%. Simultaneous efforts toward source reduction or reuse, which should be an important component of any effective waste management program, could further reduce the amount of waste being landfilled.

The introduction of a more comprehensive waste diversion plan that included compostable materials in addition to the recycling materials already listed would mean the potential for greater reduction in both the amount of waste material that would need to be landfilled, and disposal costs. If the figures from the categories of food, wood, landscape, and other organic materials were added to the materials listed above, the total potential diversion rate would be over 60% of the university waste stream.

Comparison of University and Municipal Waste Streams

The third objective of the study was "to compare the waste stream analysis for the university to the EPA/Franklin model for municipal waste streams, to highlight the types of components differences found within university waste streams." The hypothesis was:

H_0: The percentages of major components of a university solid waste stream do not differ significantly from the estimated percentages of major components of municipal solid waste streams, at a ninety percent confidence level.

H_1: The percentages of major components of a university solid waste stream do differ significantly from the estimated percentages of major components of municipal solid waste streams, at a ninety percent confidence level.

Results from student t-tests indicated the percentages of material categories in most cases were significantly different (0.90) from municipal waste streams, thereby indicating the rejection of the null hypothesis. Based on this analysis, it is clear that university waste streams contain larger amounts of paper and food than municipal waste streams and smaller amounts of glass, metal, landscape waste and wood. The amount of plastic found in the university waste stream was similar to that estimated to be present in municipal waste streams.

Breaking the university waste stream down into the three strata of academic/administrative, university apartments, and residence halls, most material categories continued to be significantly different in amount than municipal waste streams. This breakdown can serve as a basis for targeting waste diversion programs to the individual characteristics of each strata. Paper products, found in large amounts within two of the three strata, are one example of ways to use this analysis to target appropriate materials when planning waste diversion programs.

Paper was not found to be significant during the fall in the University Apartments and during the summer in the residence halls. The research makes clear that the academic/administrative units are the most consistent and largest discard source for paper products, making this strata the best focus for paper recovery programs. In addition, the academic/administrative strata contributes the largest percentage of the waste stream (51%), increasing the potential amount of paper recovery for the campus. Although paper was not found to be significant in residence halls in the summer, the greater discard rate for paper products during the school year indicates recycling programs would be more cost effective if paper pickup programs for residence halls are only active during that time period.

The amount of food waste was significantly greater than municipal systems for both the residence hall strata and the university apartments strata, and significantly less for the academic/administrative units. This shows that any program intended to divert food (organic) waste would be of most benefit for those strata that produce significantly more food waste than municipal systems, and should not include academic and administrative buildings.

For universities unable to conduct a waste characterization, this study provides insight into the composition of their waste streams and direction for planning diversion programs. Regional and methodological differences will undoubtedly result in some differences; however, this study provides baseline information and a starting point for the establishment of a recycling and integrated waste management plan.

Recommendations for Further Research:

Because the data base for this type of research is very limited, there is a great need for additional research in this area. The following studies are recommended:

1) Conducting waste assessment on other university campuses using the same protocol to see if the results are transferable to another setting.

2) Designing a waste assessment protocol with fewer material categories, to examine the theory that those categories for which very small amounts of materials are present are not accurately represented in a manual sorting protocol.

3) Conducting a similar study on the same university campus following the introduction of more comprehensive waste diversion programs, which would allow for quantification of the actual diversion rate compared to the potential diversion rate as estimated in this study.

4) Using the data from this study to estimate and compare the average cost per ton for the development and operation of waste diversion systems that a) collect easily marketed recyclables, b) collect all recyclable material and c) collect recyclables and compostibles, and compare these costs to current waste disposal costs.

APPENDICES

Appendix A

Sample Worksheet for Recording Weights of Material Categories

	Material	W 1	T1	V 1	W 2	T2	V 2	W 3	T3	V 3	W 4	T4	V 4
	Paper												
1	White Office Paper												
2	Mixed Office Paper												
3	Magazines/Glossy												
4	Corrugated												
5	Pizza Boxes												
6	Paperboard												
7	Bound Groundwood												
8	Bound Books												
9	Newsprint												
10	Junk Mail												
11	Other Paper												
	Plastics												
12	Film												
13	Clear PETE												
14	Natural HDPE												
15	Colored HDPE												
16	PP												
17	PS Foam												
18	Other Plastics												
	Glass												
19	Clear Containers												
20	Green Containers												
21	Brown Containers												
22	Other Glass												
	Metals												
23	Alum Containers/Foil												
24	Other Aluminum												
25	Steel Cans												
26	Ferrous Metal												
27	Non-Ferrous												
28	Aerosol Cans												
29	Deposit Containers												
	Organics												
30	Food												
31	Landscape Waste												
32	Other Wood Waste												
33	Leather, Rubber												
34	Residual												
35	Liquids												
36	Other Organics												

Appendix A (cont'd)

	Material	W 1	T1	V 1	W 2	T2	V 2	W 3	T3	V 3	W 4	T4	V 4
	Textiles												
37	Cloth												
38	Carpeting												
39	Other												
	Construction Debris												
40	Asphalt/Concrete												
41	Drywall												
42	Lumber												
43	Other												
	Manufactured Goods												
44	Small Appliances												
45	Clothing												
46	Furniture												
47	Other Manufact.												
48	HHW/Drugs/Med												

Appendix B

Routing Schedule for Grounds Department

GROUNDS SCHEDULE-
FALL WASTE SORT

A.M.	P.M.
<u>Monday, October 24th</u>	<u>Monday October 24th</u>
Academic/Administrative	University Apartments
<u>Tuesday, October 25th</u>	<u>Tuesday, October 25th</u>
Residence Halls	Residence Halls
<u>Wednesday, October 26th</u>	<u>Wednesday, October 26th</u>
University Apartments	Academic/Administrative
<u>Thursday, October 27th</u>	<u>Thursday, October 27th</u>
Academic/Administratives	Residence Halls
<u>Friday, October 28th</u>	<u>Friday, October 28th</u>
Pending	Pending-

Appendix C

Sample Schedule for Student Employees

A.M. Oct. 17-21	MONDAY	TUESDAY	WEDNES.	THURSD.	FRIDAY
Supervisor	Pete	Ruth	Roger	Ruth Janey	Pete Janey
Driver/ stud. sup.	Katy	Scott	Scott	Scott	Marsha
Sorters	1. Tisha 2. Don 3. Janey	1. Katy 2. Shaine 3. Matt 4. Don 5. Janey	1. Mike 2. Don 3. Katy 4. Karen 5. Janey	1. Leon 2. Candice 3. Matt 4. Shaine 5. Jeff	1. Sara 2. Tisha 3. Candice 4. Cheryl 5. Don
P.M. Oct. 17-21	**MONDAY**	**TUESDAY**	**WEDNES.**	**THURSD.**	**FRIDAY**
Supervisor	Pete Janey	Janey	Jim	Marsha	Marsha
Driver/ stud. sup.	Jim	Lori	Jim	Lori	Scott
Sorters	1. Joanna 2. Linda 3. Andrea 4. Jen 5. Mark 6. Justin	1. Dana 2. Danielle 3. Jeff 4. Andrea 5. Tisha 6. Justin	1. Sara 2. Mark 3. Andrea 4. Andrew 5. Justin	1. Katy 2. Dana 3. Danielle 4. Andrea 5. Kirk 6. Erika	1. Matt 2. Andrea 3. Linda 4. Cheryl 5. Jennifer 6. Jen

Waste Sort Training Information

Waste Sort Training

I. WELCOME!

A. Introductions
B. Why we're doing this...

II. SAFETY

A. Make sure you have all of your safety equipment, and that it is labeled
B. Sorting technique to avoid risk
C. Immunizations (tetanus, hepatitis B)
D. What to do if there is medical or hazardous waste
E. Reporting accidents

III. STRATA AND CATEGORIES

A. Three main strata we're working with
B. Waste sort categoires
  1. list of materials
  2. examples of categoires
C. What to do with "white goods" or other odd items
D. Setting up samples, Grounds schedule

IV. EQUIPMENT AND SORT PROCEDURE

A. Setting up sort containers
B. Presorting (p.m.)
C. Loading samples on sort table
  1. pull out heavy/bulky materials
  2. try to avoid adding sand to load
D. Sorting
  1. pick a group of materials and try to stay with same group
  2. one food bucket for each side of table
E. Weighing containers
  1. each person is responsible for their own containers, but please help someone else if you finish
  2. take materials to supervisor to weigh, calling off the tare and estimating volume to the nearest tenth (.1, .5, full)

Appendix D (cont'd)

3. After materials have been weighed, either empty into rolloff or appropriate recycling barrel
4. Set up containers for next sample
5. Make sure resiudal material form sort table is emptied and weighed

F. Cleanup

1. For a.m. shift, leave tale and containers out for p.m. crew unless weather inidcates no p.m. sort
2. Hang up equipment and make sure all containers are empty
3. For p.m. shift, make sure table and containers, as well as equipment, are in tent, and tent is fastened
4. Don't forget to sign the payroll sheet in the van!

V. HOUSEKEEPING

A. Payroll status

B. Schedule

1. any last minute changes?
2. who to call if you can't meet the van at Salvage

C. Transportation

1. van from Salvage
2. campus pick up
3. driving seperately

D. If the weather is bad...

Appendix D (cont'd)

WASTE SORT UPDATE

October 7, 1994

Scheduling and Payroll-
Schedules as we know them are attached to this sheet. If your schedule will be different, please let Marsha or Pete know. Payroll runs from Wednesdays to Tuesdays; please make sure you sign the payroll sheet that will be kept in the van. If you do not sign the sheet, we will not know to pay you!

Training-
There are two training sessions- one on potential pathogens and the other on waste sort procedure. It is important that you attend both of these! If you cannot attend the Friday, October 7 meeting, there are alternate dates. If you are unable to attend the Friday, October 14 meeting (from 1:00-2:30) please let us know so that we can schedule an alternate time.

Transportation-
For the morning shift, we plan to be at Granger at 8:00. The van will leave Salvage at 7:40, and swing by Wells Hall at 7:45 before heading to Granger. If you have made alternate arrangements for transportation, please let the student supervisor for your shift know. The morning shift will be leaving about 11:45 to go back to Wells Hall at 12:35, and head out to Granger. Again, if you need to drive separately, let us know. The afternoon shift will be leaving Granger about 4:40 to swing by Wells Hall and back to Salvage. There is parking available at Salvage.

Clothing-
Long pants and long-sleeved shirts are recommended for safety reasons. Please also wear closed-toed shoes with firm soles. On rainy days, boots are recommended. Coveralls, filter masks, gloves, goggles and hats wo;; be provided. You may want to bring an extra pair of shoes, so you can leave your "sorting shoes" on site.

Food/Drink/Hygiene
Drinking water will be available, as well as a cooler if you wish to bring other beverages or snacks. There is a bathroom and sink available, although not directly on site. We will try to find a storage system so that gear may be left in the tent between shifts.

Appendix D (cont'd)

WHERE SHOULD IT GO?

Here is a list of some items that are commonly found, and the category they should be placed in:

Batteries	**HHW**
Beverage containers, carbonated	**Deposit containers**
Beverages containers, non-carb.	**By container type**
Metal can lids	**Steel cans**
Candy wrappers, chip bags	**Film**
Ceramic dishes or vases	**Other glass**
Cleaning supplies, partially full	**HHW**
Cleaning supplies, empty	**By container type**
Curling irons/hair dryers	**Small appliances**
Chairs, desks, stools	**Furniture**
Cleaning sponges	**Other plastics**
Computer paper	**White office**
Computer paper, groundwood	**Mixed paper**
Diapers	**HHW**
Envelopes with windows or unopened	**Junkmail**
Lab glassware (Pyrex, Kimax)	**Other glass**
Latex paint cans	**Other CD**
Linoleum/molding	**Other CD**
Masking Tape, in wads	**Other CD**
Cereal boxes (unopened)	**Other Manufactured**
Cereal boxes (half full)	**Food**
Cereal boxes (empty)	**Paperboard**
Paper towels	**Other paper**
Pens/Pencils (Usable)	**Other Manufactured**
Phone books, schedule books	**Bound groundwood**
Prescription Medications	**HHW**
Shoes (Usable)	**Other Manufactured**
Shoes (Unusable)	**Leather or Plastics**
Window or plate glass	**Other Glass**

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