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AUTHOR Boyd, Gail B.; Hawkins, Myron B.
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ABSTRACT

The project summarized by this report involved a preliminary design of a model for estimating and predicting the quantity and composition of solid waste and a determination of its feasibility. The novelty of the prediction model is that it estimates and predicts on the basis of knowledge of materials and quantities before they become a part of the solid waste stream. The project elected to test feasibility in the area of residential solid waste. Because of the complexity resulting from the countless items that enter the average home, it was felt that this area of study would most likely highlight the weakness of the technique. Results of the study seem to indicate that the model performed quite well. Although the approach involves certain difficulties in implementation and maintenance in the residential sector, this is not necessarily true for the commercial sector. Stories deal more in bulk than residences do, and consequently, complexity is reduced. Details of the model and a discussion of its advantages and shortcomings are presented. (JP)

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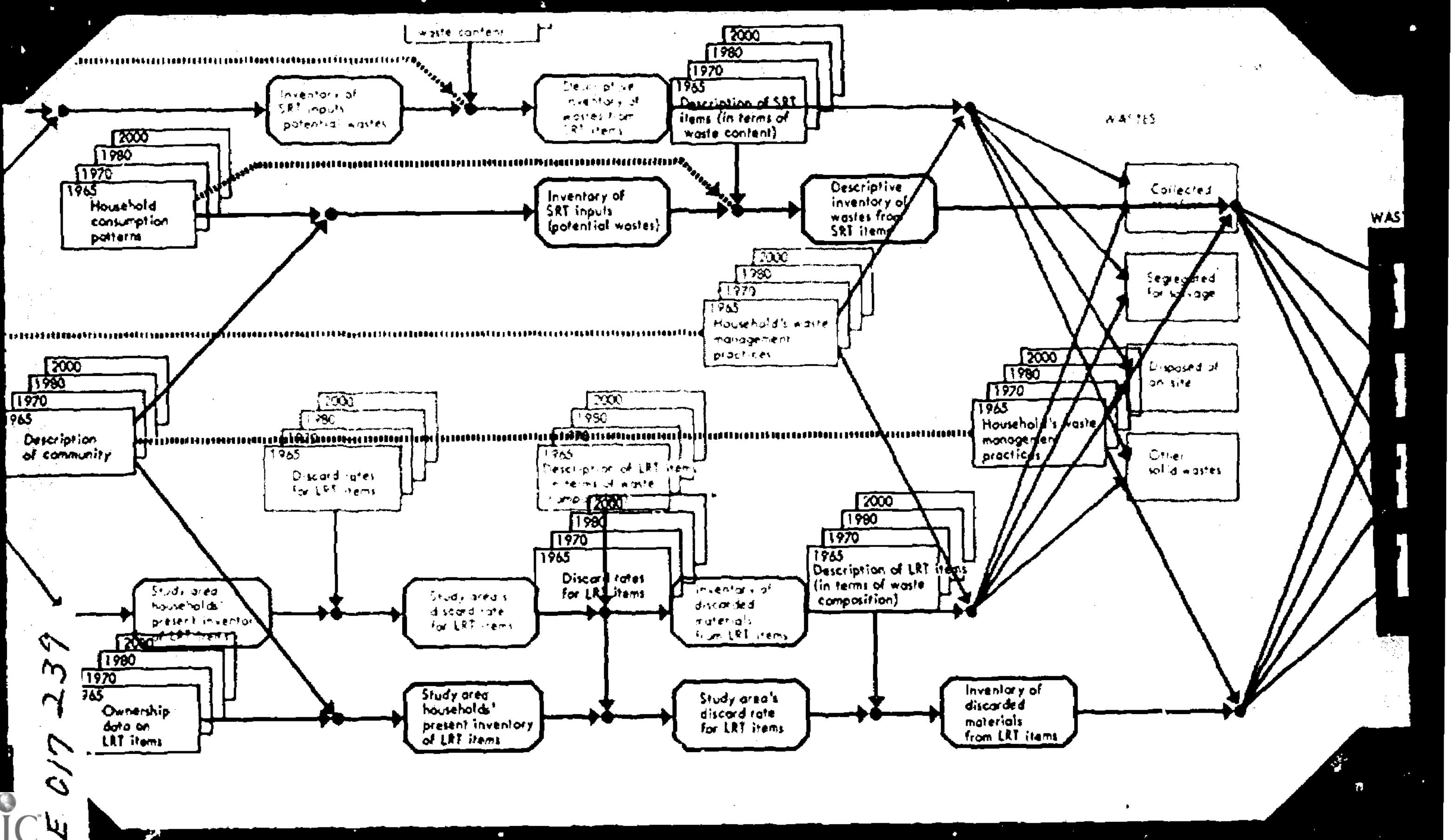
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METHODS OF PREDICTING SOLID WASTE CHARACTERISTICS

This report (SW-23c) was written by
GAIL B. BOYD and MYRON B. HAWKINS
URS Research Company, San Mateo, California
for the Federal solid waste management program
under Contract No. PH 86-68-98

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FOREWORD

INFORMATION ON THE QUANTITY AND COMPOSITION of solid waste is indispensable in designing, implementating, and operating the solid waste management systems of today and in forecasting the requirements of the solid waste systems of tomorrow. Presently, methods of estimating and predicting the quantity and composition of solid waste are most commonly based upon direct measures such as sampling of solid waste itself. There are, however, several disadvantages in the direct approach: (1) Sampling at disposal sites does not provide adequate information regarding the source of the waste. (2) It is difficult to recognize and identify solid wate components in samples. (3) Discard rates for certain solid wastes are too discontinuous, relative to time, to provide meaningful samples unless the sampling itself is done over an adequate period of time. (4) Sampling does not provide the insights necessary to predict future solid waste quantities and compositions.

The project summarized by this report involved a preliminary design of a model for estimating and predicting the quantity and composition of solid waste and a determination of its feasibility. The concept employed is, however, a novel one. Rather than utilize direct measures, the model estimates and predicts on the basis of knowledge of materials and quantities before they become a part of the solid waste stream, together with an understanding of the process by which materials become solid waste. Such a model accomplishes by synthesis what direct measures seek to accomplish by analysis. The synthetic approach partially or totally overcomes the disadvantages previously mentioned for direct sampling of solid waste.

The project was directed to a study of residential solid waste, the most complex area of all in regard to this new technique because of the countless items that enter the average home, many of which are small or insignificant. Thus, the project elected to test feasibility in the area most likely to highlight the weaknesses of the technique. In point of fact, however, the preliminary design performed quite well. Although the approach involves certain difficulties in implementation and maintenance in the residential sector at this time, this is not necessarily true for the commercial sector. Stores deal more in bulk than residences do, and consequently, complexity is reduced. Further, commercial establishments maintain detailed inventories, something the homeowner does not do. The model developed is, therefore, especially attractive for estimating and predicting the quantity and composition of commercial solid waste on a community-wide basis, hitherto a most intractable problem.

The contributions of the project officer, Albert J. Klee, Bureau of Solid Waste Management, to this study are gratefully acknowledged, as are those of Professor John Heer, University of Louisville, and the editors of *Life* magazine.

–RICHARD D. VAUGHAN

Deputy Assistant Administrator
for Solid Waste Management

CONTENTS

METHODS OF PREDICTING SOLID WASTE CHARACTERISTICS

The design, implementation, and operation of efficient and economical solid waste collection, handling, transport, and disposal systems require accurate information on the quantities and characteristics of the solid waste to be processed. This information is needed for the present and for the lifetime of a waste management system. The overall objective of the study reported herein was to develop methods that can be applied to real (or hypothetical) cities, counties, and regions for estimating the quantity and character of the solid wastes generated at present and at various times in the future.

The work was planned to be implemented in two phases. Phase 1 was the preparation of preliminary design of the prediction model and a determination of its feasibility. The second phase was the development of the model, preparation of the associated computer programs, assembly of appropriate data banks, and conduct of test runs for specific areas. This report describes the work undertaken in the first phase, including the results, our conclusions, and our recommendations regarding the concepts and approaches for the work to be performed in the second phase of the study.

Within the scope of work as specified in the contract for phase 1, URS Research Company undertook four major tasks. The first was to develop specifications for, and to design, the basic waste prediction model. This necessitated establishing an output information format pertinent to the anticipated use of the data and placing particular importance upon the degree of detail in description of materials, location of waste, and the time at which waste is produced. Concomitantly, sources of information on input commodities and activity characteristics were identified and investigated, and the type and quality of available information were defined. Output specifications were compared with input data availability, and a compatible model was developed.

The second task was to collect, develop, and formulate selected standard data, descriptors, and functions for input commodities and activities. This involved an analytical study of materials, commodities, community activities, and waste production. Although much information was presumed available, it needed modification to the format used in the model. Various sources were to be evaluated relative to prediction of the character of commodities in the future. One of the information items anticipated to be somewhat difficult to obtain was the "residence time" data. In the initial study, only a selected spectrum of input commodities and activities was to be evaluated.

The third task was to test the model manually in a small community. This test was to be used to evaluate the general performance of the model. Manual computation was to be used to avoid costly programming and computer time while the model was in a preliminary stage of development. A small community or a segment of a community was to be selected with information on the quantity of input materials to be obtained. The waste characteristics would be predicted and compared with data collected at disposal or other sites. The basis for the selection of the sample was to be its capability of providing a significant sample of the most important prediction parameters.

Finally, the test results were to be evaluated in order to judge the practicality of the model, the possible accuracy and precision of the system, and the limitations to the system.

SUMMARY

The basic concept of the solid waste prediction model developed in this project is that the waste generated by a community is derived primarily from the goods and materials consumed by the community; therefore waste quantities and characteristics can be estimated from information concerning the consumption habits of the community and the manner in which it uses and consumes the material obtained. Such an approach facilitates the prediction of future waste characteristics because of the widespread availability of information concerning the production, use, and composition of goods and materials in the future.

The study consisted primarily of determining the availability of usable information and developing a preliminary prediction model for residential-household solid wastes. This model was restricted to the prediction of present-day, short-residence-time wastes. Its performance was tested by comparing its predictions for a given locality with the results of an actual study of solid waste generation in that locality. The areas studied were in Jefferson County, Kentucky. Pertinent demographic data were collected and the solid waste quantities of various materials estimated by manual application of the prediction method. The results compared favorably with the measured values (Table 1).

Table 1. Quantities of selected waste materials generated in test community (areas of Jefferson County, Kentucky) (lb/HOUSEHOLD/wk)

	Measured by Univ. of Louisville study		Estimated by URS prototype model
Material	Low	High	
Paper	24.9	37.8	23.43
Glass	3.8	6.7	2.54
Metal	3.9	6.0	4.23

It is recommended that additional work be performed to achieve further results. The first objective would be to complete the development of the residential-household-prediction model, to modify it to include institutional and commercial activities, to computerize the model, and to run a test case. The second objective of the additional work would be to perform a preliminary development and feasibility test with methods similar to those used for predicting household wastes and for predicting industrial, agricultural, and other selected wastes.

DISCUSSION AND GENERAL APPROACH

An intimate knowledge of the composition of the waste is needed as a basis for the design of waste management systems and for the planning of research and development for solid waste-handling and treatment processes. The technical feasibility of incineration, composting, and other processes; the operational practicality of collection, segregation, and secondary-material recovery systems; and the economic feasibility of all aspects of waste handling require detailed information regarding the source, quantity, and quality of all waste materials. In order to perform such studies effectively, the changes in characteristics of waste materials (resulting from population growth, land use modification, and technological changes in material properties and industrial processes) must be predicted for several decades.

The usual method of obtaining data on waste characteristics and quantity is by physically inventorying the materials delivered to the disposal site. Whereas such an approach provides information that can be useful in formulating immediate solutions to current problems,* its use as the primary basis for defining and solving long-range problems is suspect for four major reasons. First, inventorying present and past wastes cannot serve as a basis for predicting future waste characteristics or quantity, since it does not account for any of the technical, social, economic, or other factors that influence waste generation. Second, the difficulty of segregating and identifying waste components (after they have been stored, compacted, transported, and repeatedly handled) severely reduces the accuracy of any quantitative description. Third, studies conducted at the disposal site generally do not provide adequate information concerning the sources of waste. Fourth, the discard rate for many types of waste is too discontinuous (relative to time) to allow conventional surveys to obtain sufficiently representative samples.

The present study is concerned with a waste prediction technique based on the following hypothesis: that the wastes discarded by a community derive primarily from the materials purchased, consumed, and used by that community (i.e., "inputs"); therefore, one can predict the amount and nature of these waste "outputs" by identifying what goods and materials

*Data derived from conventional waste measurement and analyses have been valuable to the present study in that they provide baseline waste generation information and indicate where better definition is needed.

constitute the community's inputs and by knowing how the community acts upon these inputs.

It is implicit in this hypothesis that studying the characteristics of commodities, materials, and products with their "consumption" by society will reveal information about the resulting waste. Note that the time required for a given material to pass through the community is an important consideration and varies widely for different materials (or products) according to the uses to which they are put. Some input materials, such as foods, are received, distributed, and consumed and become waste in a matter of hours or days. Other products, such as those used in construction, may be resident in the community for half a century or longer before they become waste.

In a discrete community, the input materials may be acted on by the community by consuming, processing, or generating (Table 2). The community may *consume* them, eventually converting all the input materials to waste. For example, a case of canned vegetables (consisting of solid food, liquid food, metal cans, and a fiberboard box) entering a community will be converted entirely to waste within a few weeks.* The community may *process* them for consumption elsewhere, with only a fraction's becoming waste in the community. For example, most of the steel and plastics shipped to a manufacturing plant will leave the area, their only trace in the community being the small amount of production scrap and the few units sold in the area. The community may *generate* materials, in the sense that agricultural crops, vegetation, and livestock are grown and resources are obtained from mines and wells. In most cases, the materials generated within the area are consumed outside the area, although waste materials will remain in the area.

Obviously, not all activities are exclusively in one category or another. For instance, all processing and generating activities are also consumers of some input materials but to a lesser extent.

Estimation of the solid waste materials produced by any given community, through use of the concepts proposed herein, primarily involves inventorying all waste-producing activities in the community; compiling standard information on the materials consumed per unit size per unit time by each type of activity and information on which of these materials become solid wastes; and determining the rate of solid waste production from this information.

*For purposes of predicting solid wastes, only the packaging materials are of interest.

Table 2. Significant community activity classifications**

Consumption activities
- Residential household (single-and multiple-family dwellings)
- Financial and business establishments (including government activities)
- Institutions
- Restaurants
- Utilities (including water and waste treatment)
- Transportation

Processing activities
- Industrial:
  - Food processing
  - Manufacturing of durable and nondurable goods
  - Chemical manufacturing, processing, refining
- Construction
- Commercial (retail and wholesale marketing)

Generation activities
- Agriculture
- Mining (including petroleum)
- Commercial fishing
- Demolition
- Miscellaneous (e.g., street sweeping, gardening)

**These classifications relate closely to those of the Bureau of Budget's Standard Industrial Classification, and to the system proposed by the Urban Renewal Administration and the Bureau of Public Roads for land use classification, and thus facilitate the use of the vast amount of data available from the Federal Government.[1,2]

Information on the rate of material consumption (and, therefore, waste generation) by each type of activity is derived from many sources and is based largely on descriptions of the material input-output characteristics of the processes used by each activity. Although the actual computations and data bank formulations vary somewhat, depending on the type of activity being considered, a basic computational approach is applicable (Figure 1). The four basic data banks of the model are described here:

Description of Community. This is a data bank that provides an inventory of each type of activity in the study community, as well as their number, size, and location.* This is actually an inventory of waste sources.

Description of Standard Activity. This is a data bank that indicates for each type of activity the amount of waste items** and materials produced per unit time per unit size of activity. This data bank would be of a general nature and would apply to the study of any area of the country.

*Location refers here to census tract, enumeration district, county, urban area, or some other segment of the area being studied.

**In the terminology used herein, "waste item" refers to a recognizable, discrete object made up of one or more materials. For example, a discarded television set or sofa is a "waste item." A "waste material" is a more specific classification of waste content, e.g., glass, copper, paper, wood, or textiles.

Standard Waste Composition Data. This signifies a standard data bank that provides the information needed to convert a unit of input item into the quantities of waste materials it will yield. For example, N lb of coffee would be converted to X lb of granular solids, Y lb of metal (from the can), Z lb of plastic (from the lid).

Local Waste Management Practices. This is a data bank that provides information on the manner in which specific wastes from specific sources are ultimately disposed of by the community (i.e., whether they are collected as refuse, segregated for salvage, disposed of on site, or otherwise eliminated). This information is specific for each community and reflects both the habits of the residents and the legal restrictions on disposal practice.

Two intermediate compilations result from the various computations (Figure 1).

Total Waste Inventory. This lists the quantity of all waste items produced in each location within the study area. It is derived from the first two data banks.

Descriptive Inventory of Solid Wastes. This lists the quantity of each waste item and waste material likely to end up as a "solid waste." Solid materials while airborne or waterborne are eliminated from consideration.[1] This information is derived by using additional process data from the Activity Description and from Waste Composition Data to develop the waste material inventory.

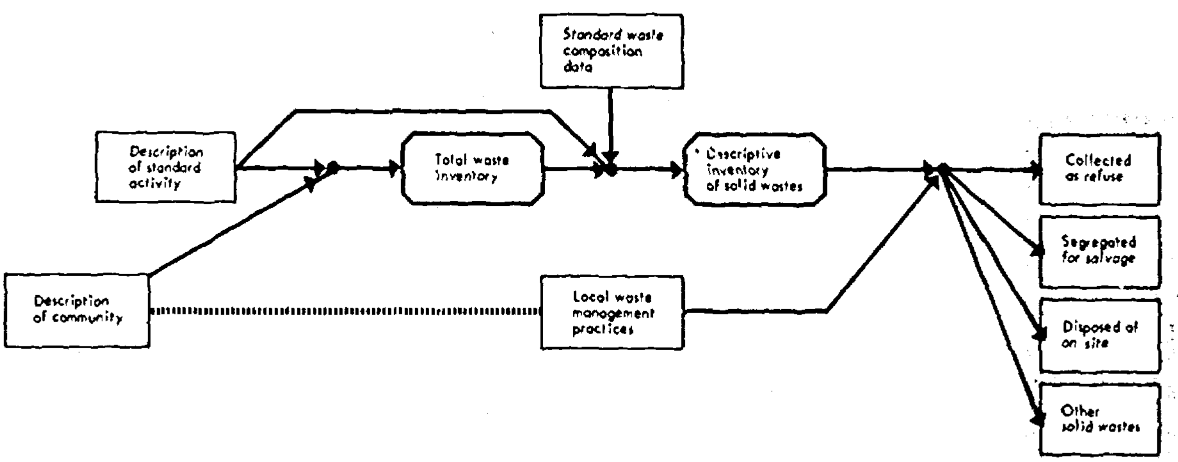

Figure 1. A conceptual overview of the basic solid waste prediction model. The separate models for predicting the wastes from each type of activity would differ somewhat, but would all share this basic format. Rectangles represent basic data banks. Irregular octagons represent the intermediate compilations arising from the various computations. Shaded rectangles are a series of compilations, the final output of the model.

The final output of the model is a series of four compilations (Figure 1).

Inventory of Wastes Collected as Refuse. This inventory lists the quantities of waste items and materials normally collected for disposal.

Inventory of Wastes Segregated for Salvage. This lists the quantities of waste items and materials segregated (by the activity) and either recycled within the process or collected separately for reuse, resource recovery, or salvage.

Inventory of Wastes Disposed of On Site. This is a compilation of the quantities of waste items and materials disposed of by the activity itself. This would include, for example, materials burned in an incinerator, ground in a garbage grinder, buried, or otherwise processed for disposal.

Inventory of Other Solid Wastes. This list includes those waste items and materials not elsewhere accounted for.

The wastes are tabulated in two ways: by the amount of each *item* (e.g., pounds of tin cans, washing machines) and by the amount of constituent *material* (e.g., pounds of paper, ferrous metal, plastic). This appears to meet the requirements of the initial uses of the model. It will probably, however, be useful to introduce further calculations (not shown in Figure 1) to convert the basic waste inventories so that they reflect other waste characteristics, such as calorific value, biochemical degradability, chemical composition, bulk density, real density, and unit size.

A more specific version of the basic prediction model applicable to residential households would need to redefine some data banks in relation to the household activity function and to incorporate consideration of two important aspects of the ultimate computational procedure. The wastes from short-resident-time (SRT) items must be predicted separately from wastes from long-residence-time (LRT) items.* Data banks required for predicting waste quantities and characteristics at selected times in the future must be included (Figure 2).

In this study, no specific useful-life duration was established to differentiate between SRT and LRT items. Items "consumed" within a year or less are generally considered, however, to be SRT items. Even without a rigidly established criterion, little difficulty was experienced in assigning items to one category or the other.

Separating the prediction processes for SRT and LRT wastes is necessitated by two basic factors. First, household inventories of LRT items tend to increase; therefore, a purchase of such an item does not necessarily result in the immediate discard of a like item, as distinguished from SRT items, which are used essentially immediately and become waste in the same general period in which they are procured. Second, because the material characteristics of many LRT items change with changes in technology, and since those being discarded today were manufactured 5 to 15 years ago, special consideration must be given to the material characteristics of the item. The means of predicting both LRT and SRT wastes are discussed in detail in a later section.

An important use of the prediction model is related to the estimation of waste characteristics in the future. To use the model for such a purpose requires predictions and forecasts of future changes in the following: descriptions of communities; household consumption patterns (and descriptions of standard activities); composition of SRT and LRT items; household waste management practices; ownership data on LRT items; discard rate data.

Generally, the most valid predictions of changes in materials, products, and technology are those made by persons having the best knowledge of the specific technologies and industries involved. Similarly, the most important predictions of the growth and change of a given community are those by the responsible authorities within the community. The method used (that of having essentially separate data banks for each predictive year) was, therefore, chosen partly because it provides a means of incorporating independent predictions from different sources.** At present, it is planned to use 1965 as the base year with 1970, 1980, and 2000 as projection years. In applying the model, only 1 year would be considered at a time. Although forecasts are available for many specific items of information (e.g., estimates of their anticipated growth made by communities), it may be possible and desirable to develop specialized models (and computer

*LRT items are those that tend to remain in use (or at least in "storage") in the normal household for a relatively long time. Examples would include furnishings, appliances, books, tools, and the like. Examples of SRT items would include food, periodicals, most clothing, and disposable paper and plastic goods.

**The problem remains, of course, of ensuring that independent predictions are reasonably compatible. This would be done at the time the predictions are evaluated and the data banks prepared.

programs) to forecast systematically the growth of selected activities. The specific means of generating these forecasts is not within the scope of this study.

During this phase of the study, a detailed diagram of the household waste prediction model was developed. It followed the general format already discussed but employed several minor modifications. This prototype model concentrates on SRT items and considers but one time period (i.e., it cannot make forecasts of future wastes).

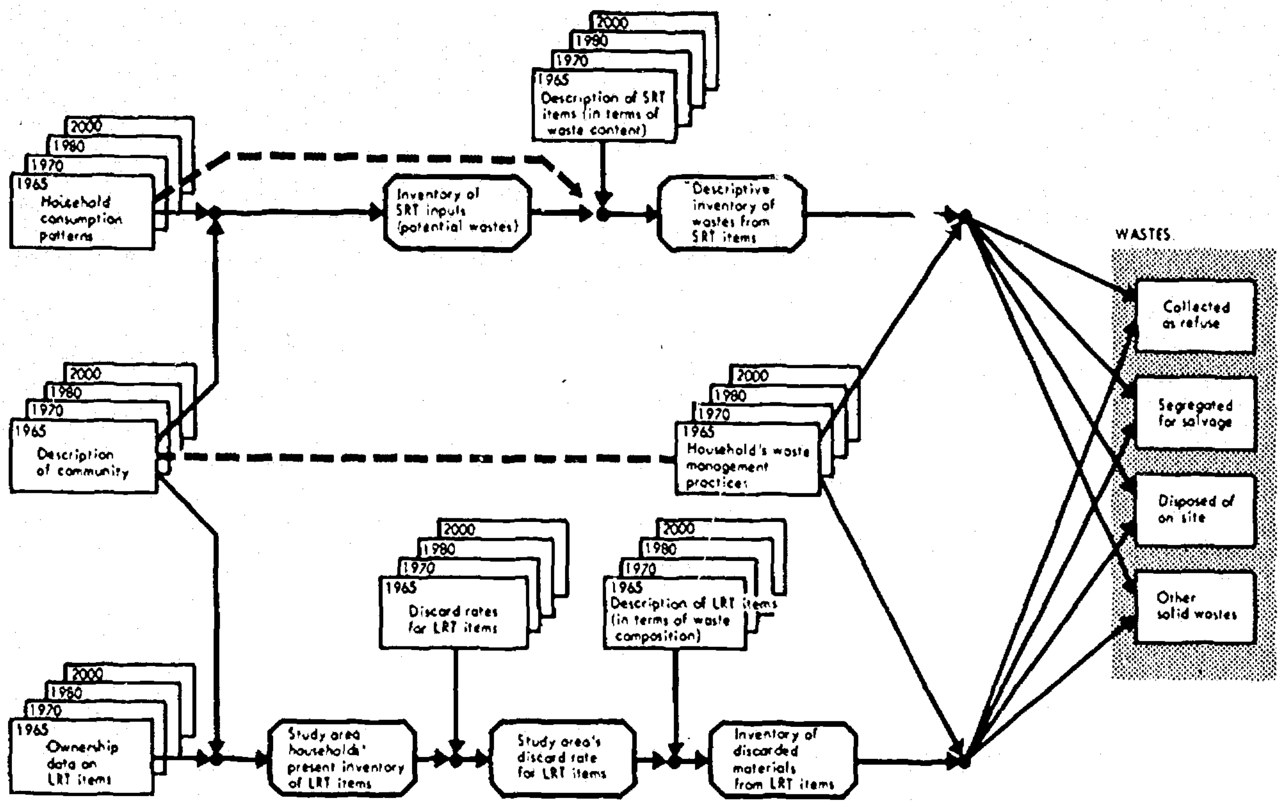

Figure 2. The household-solid-waste-prediction model, which was expanded to account for long-residence-time and short-residence-time items separately.

HOUSEHOLD-WASTE PREDICTION TECHNIQUE

The household-waste problem was chosen as the subject for this preliminary development and feasibility study because in many ways it embodies the most complex prediction problems. In addition, the collection, transport, and disposal of household waste represent the most costly and widespread waste management problems, and their effective solution is dependent on useful waste characteristic data.

The basic computational model developed for household-waste prediction has been described (Figure 2). Although the model is large in that it handles a sizable amount of numerical data concerning expenditure rates, consumer item descriptions, use patterns, and disposal practices, it is simple in that only basic arithmetic functions are used in manipulating the data.

The general aspects of the computational model are discussed here, and the specific application of the model is described in a later section.

Bases for Household-Waste Model

The fundamental element of the household-solid-waste prediction model is the data bank entitled "Description of the Community" (Figure 2). The number of persons living in each area of the community is, of course, the community characteristic most pertinent to the household-waste problem, and this information is readily available from the Bureau of Census. Additional descriptors, such as number of families and income distribution among families, provide information pertinent to the consumption habits of the residential sector.

The "Description of the Standard Activity" is a data bank that indicates the quantitative input-output characteristics of the activities—in this case, the residential household. During the initial phases of the study, several approaches to determining the "input" materials to a community's households were investigated, including consideration of the means of inventorying the shipments into the community, the shipments to wholesalers and distributors, and so on. From a review of available information, however, it became obvious that studies of consumer buying habits would be the most practical sources of data. Of the various studies of this type, the most applicable one encountered was a report entitled "Expenditure patterns of the American family."[3] The report was prepared by the National Industrial Conference Board in 1965 under the sponsorship of *Life* magazine, and it will be referred to herein as the "*Life* study." Based upon statistical data collected as part of an unusually comprehensive series of surveys of consumer behavior conducted by the Bureau of Labor Statistics, U.S. Department of Labor, it contains a vast quantity of data on the rate at which households spend money on about 700 different goods and services (Table 3). The important feature of this study is the information on the manner in which each of these expenditures varies

Table 3. Major expenditure categories*

Major expenditure categories	Number of items listed**	Major expenditure categories	Number of items listed**
Food, beverages, and tobacco		Local transportation	1
Cereals and bakery products	23	Intercity transportation	6
Meats, poultry, and fish	18	Other transportation expenses	5
Milk, cream, and cheese	11	Medical and personal care	
Fruits and vegetables	47	Group plans and insurance	3
Other foods	56	In-hospital care	3
Alcoholic beverages	5	Professional services	3
Tobacco	4	Drugs and medicine	6
Housing and household operations		Other medical care	1
Shelter and other real estate	17	Personal care services	5
Household operations	22	Personal care supplies	14
Household supplies	20	Recreation and equipment	
House furnishings and equipment		TV, radios, and musical instruments	10
Household textiles	14	Spectator admissions	4
Furniture	11	Participant sports	3
Floor coverings	8	Club dues and memberships	1
Major appliances	18	Hobbies	5
Small appliances	4	Toys and play equipment	7
Housewares	12	Recreation out of home city	1
Miscellaneous items	11	Other recreation	1
Clothing and accessories		All other goods and services	
Clothing (aggregated by sex and age)	142	Reading	6
Clothing materials	1	Education	4
Clothing upkeep	3	Other current expenditures	4
Transportation		Additional disbursements	7
Automobile purchase	2		
Auto–operating expenses	10		
Auto insurance	5	Total number of items and	
Repairs and parts	1	aggregations of items listed = 566	
Other auto expenses	1		

*These catagories are handled as separate parameters in the *Life* study (Ref. 3).

**Some of these "items" are actually aggregations of related individual items. For example, the following aggregation is listed as a single "item" of men's clothing: suits, sport coats, and trousers.

relative to factors such as family size, family income, and geographical region (Table 4).

One limitation of the *Life* study, relative to its use for waste prediction, is that the results are reported in dollars expended. Consequently, a considerable portion of the research effort was directed toward converting the reported expenditure rates into material input rates. The *Life* study states how many dollars are spent (per household per week) on common consumer items, such as canned coffee. Consequently, it was necessary to obtain sufficient additional information to convert this dollar expenditure figure to pounds of steel can, pounds of plastic lid, and pounds of spent coffee grounds (per household per week), since these are the potential solid wastes.

Other major tasks involved deciding whether or not these potential wastes actually become waste, how this occurs, and what form the wastes take. These factors depend upon how the household processes the "input" material. For most items, information concerning use patterns came from a general knowledge of household operations, rather than from formal data sources. The details on the means of obtaining and manipulating the various types of information concerning each input in

Table 4. Household characteristics*

Household characteristics	Number of categories listed
Age of head of household	6
Stage in life cycle (indicates ages of children)	6
Family size	5
Family income	6
Earner composition (identifies breadwinners)	4
Occupation of head of household	6
Geographical region	4
Race	2
Market location (proximity to metropolitan area)	5
Home tenure (owned or rented)	2
Education of head of household	5
Total number of categories listed =	51

*These household characteristics are handled as separate parameters in the *Life* study (Ref. 3).

order to obtain final waste generation predictions are discussed in the following paragraphs.

Prediction of LRT Items. A major problem, as previously indicated, arises from the necessity of predicting the disposal of items that have a relatively long useful life. In actuality, today's household waste consists of three major fractions: SRT items, including their packages and containers, that have been purchased recently; the containers and packaging materials accompanying the LRT items that have been purchased recently; LRT items purchased in the past. Although the *Life* study data provide information that can be used as a basis for the predictions of waste from the first two items, they are not useful for the prediction of the third, since the purchase of a new LRT item is not automatically accompanied by the discard of an older one.

The following characteristics, common to many LRT items, make prediction of their waste characteristics difficult: their discard rate is difficult to estimate because of the tendency to increase the per capita resident inventory of many items; many items discarded by one population group are reused by other population groups in different locations before finally being discarded as refuse; technological changes in manufacturing processes, product design, and materials have resulted in changes in the composition of many items.

The first of these characteristics is related to a number of factors, including: a general increase in disposable income; a continuing reduction in the base price of many LRT items; the occurrence of buying trends based upon status and affluence motivations; the low salvage value of outmoded but still operable items.

Television sets are a good example of this tendency. When television was first introduced, ownership was quite limited, whereas now virtually all families own a set, and many own two or more. Television ownership has risen from 20 percent of all families in 1950 to more than 93 percent at present.[4] Many other items (e.g., radios, small appliances, boats) also show an increased per capita inventory.[5] The tendency of many families to maintain more than one residence (e.g., vacation homes) also complicates the prediction procedure.

The fact that many LRT items can be put to use by someone other than the original purchaser complicates waste prediction in that it interferes with determining the location at which the item will ultimately be discarded as waste. This problem also interferes with estimating the useful life of many items.

The third problem, that of introducing composition changes into the program, is not overwhelming. Actually, most of the significant changes appear to have occurred rather recently, and their general characteristics can be inferred from trade literature. The problem is largely related to obtaining sufficiently accurate "average" composition information for the various items.

Specific methods of predicting the quantities and characteristics of yesterday's LRT waste have not been developed to date. The major problems have, however, been identified and several concepts have been briefly explored. The computational procedure is believed to be conceptually correct (Figure 2). The data bank "Ownership Data for LRT Items" is used to indicate the quantities of durable goods used or stored in typical households of various economic levels. This type of information is available from the Bureau of Labor Statistics, Bureau of Census, and various non-governmental sources, although it must be evaluated and coordinated before use.

The data bank "description of LRT Items" will be more difficult to develop. The desired output "number of each type of items of X years' average age discarded per household per unit time" can probably be derived for many items from production and ownership data. The derivation, however, will be somewhat laborious and time consuming unless a computer program is developed to assimilate the available data.

The data bank "Discard Rates for LRT Items" will provide information on the composition of the discarded LRT items. The format of the information is dependent on the output of the "discard rate" data and the assumptions concerning the composition of LRT items of various sizes, types, ages, and brands. This information will be costly to collect if the accuracy requirements are demanding.

As previously indicated, no computational procedure for prediction of LRT waste was developed and used as part of this study. Its development will be an important initial aspect of our subsequent work.

Quantities of solid waste derived from SRT household items have been estimated by means of a computational approach.

HOUSEHOLD-WASTE PREDICTION MODEL

The following discussion examines various portions of the household-waste prediction model and explains their content, function, and relationships (Figure 3). To some extent, the description relates more directly to the methods used for the manually performed case study, rather than those that will be developed for eventual computer solution.

Prediction of Input Items

Summary of Expenditures. Block *c* is the result of the initial computation. It indicates the amount of money all households in a study area will spend collectively on each of a large number of consumer items. The expenditures are expressed in terms of "dollars spent per unit time" and are tabulated on an item-by-item basis (e.g., expenditure rates for bread, soap, and floor wax are expressed separately). This expenditure summary is based upon information regarding the way an individual household of a particular type spends money on various items (Consumer Expenditures by Household, block *b*) combined with information on how many households of each type are located within the study area (descriptive information on households in study area, block *a*).

Consumer Expenditures by Household. These data (block *b*) were obtained primarily from the *Life* study described previously.[3] Data are expressed in terms of "dollars spent per household per unit time" and are tabulated on an item-by-item basis. The data in the *Life* study are presented in the form of a large matrix, the row headings being items, the columns being household characteristics. The body of the matrix itself consists of the expenditure rates each type of household will have for each particular item listed (there are tens of thousands of such rates listed, all given to the nearest cent per week). In the present study the major groupings of the *Life* report row and column headings were listed. In summary, a wide variety of information is available, but generally only those data relatable to income and section of the country were found to be directly applicable.

The Community Description. Block *a* provides information on the demographic and socioeconomic nature of the study area. The following factors were found to provide the most useful information on the people and the activities in the study area: population; population density; average size of household; distribution of income; number, size, and type of establishments (wholesale and retail trade, selected services, manufacturers, mineral industries, agriculture). For any given study area, the most desirable sources of such information might differ somewhat but would generally include the U.S. Department of Commerce (especially the Bureau of Census and the Business Defense Services Administration); the U.S. Department of

Labor (Bureau of Labor Statistics); the State departments of commerce; local chambers of commerce; various State and local agencies concerned with commercial and industrial development.

Inventory of Input Items. Block *j* is computed by multiplying the expenditure per unit time for each item (from Summary of Expenditures, block *c*) by the unit cost of the corresponding item (Price per Unit Amount Conversion Factors, block *d*). Thus, block *j* gives the number of units of each item entering the study area per unit time. The amounts are expressed in terms of whatever units of measure are most appropriate for the particular item (e.g., dozens of eggs, loaves of bread, pounds of coffee, pairs of shoes).

Price/Amount Conversion Factors. These data (block *d*) are derived in a subroutine that establishes the average price per unit amount, the different sizes and types of units commonly produced and marketed being taken into account. This subroutine is also used to estimate the "average composite package unit," which is used in a subsequent computation. The data for these subroutines come from a wide variety of sources, including surveys. Care must be taken to ensure that costs are taken for a common year; in addition, regional variations may have some effect on cost.

The preceding discussion has been limited to that portion of the model pertaining to the development of the inventory of input items to the household and is applicable to all inputs other than LRT consumer items, i.e., SRT consumer items; the containers and packaging materials that accompany SRT items; the containers and packaging materials that accompany LRT items (Figure 3).

Prediction of Potential Wastes

The following paragraphs are concerned with the means of using the input inventory to develop waste predictions.

Block *i* of Figure 3 represents a tabulation of information that describes each item in terms of its *material composition* (i.e., pounds of glass, steel, plastic, paper, etc). It is at this point in the model that each item's consumption rate would be defined in more detail. For example, W lb of coffee per week would be defined as X lb of granular solids, Y lb of tin-plated steel cans, Z lb of plastic lids. These values will be the "average" for a composite unit size package and will be based on the market coverage (i.e., distribution) of sizes and types of packages. For example, 50 lb of coffee cannot be interpreted as 50 cans of 1-lb size. Rather, it will consist of some mix of 1/2-, 1-, 2-, and 3-lb metal cans, plus some mix of special paper bags. Since each of these alternative containers will affect the household waste differently, it was necessary to devise a simple method to account for them. The method used here was merely to construct a hypothetical "pound of coffee," *m* percent of which comes in one size and type of container, *n* percent of which comes in another size and type, and so on. An alternative method would be to consider every size and type available on the market as a separate item, but the problems of data storage (and availability) rule out this approach immediately. In this study, descriptive information was obtained primarily by collecting, disassembling, and weighing a multitude of items and their associated containers and packaging. The marketing information of blocks *f*, *g*, and *h* provides a basis for assigning weighting factors that reflect the relative importance of various sizes and types of items available (i.e., the example of ground coffee being considered again, marketing information[16] indicates that major emphasis should be placed upon the 1- and 2-lb cans and only minor emphasis on bags).

Combining the Input Item Inventory (block *j*) with the description of each item (block *i*) yields a Descriptive Inventory (block *k*) of the material that enters the household. This inventory indicates, in separate tabulations, both materials and items that enter the household.

The Waste/Item Conversion Factor (block *l*) is introduced to indicate the primary fate of materials that enter the household. The various alternatives are as follows: solid waste; airborne wastes (e.g., aerosol-type hair spray, air deodorants); liquid, i.e., sanitary waste (e.g., cleansers, food, tissue); distributed within residence so as to be "lost" (e.g., floor wax); distributed outside residence so as to be "lost" (e.g., fertilizer, pet food); prolonged "storage."

Those items not entering the solid waste stream must be carried in the original inventory because of the need to include their containers as solid waste. It is anticipated that in the computerized model this function will be included in block *h*, the data bank that gives the composition and content of items. Applying the waste/item conversion factors of block *l* to the inputs (i.e., combining blocks *k* and *l*) yields the Descriptive Inventory of Potential Waste Items and Materials (block *n*).*

*Note that the waste materials listed in this inventory are still keyed to the parent item from which they originated.

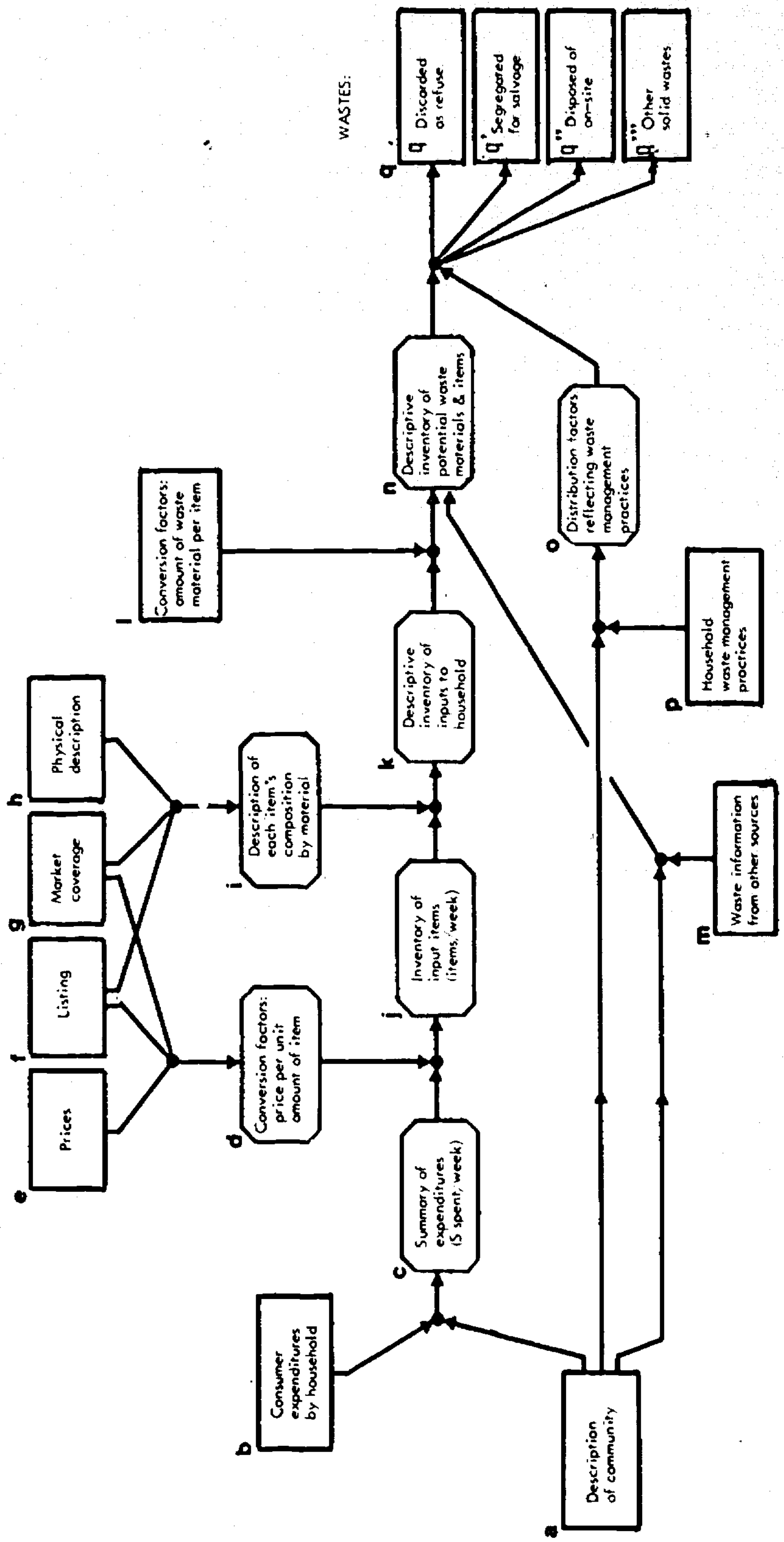

Figure 3. Household solid waste prediction model.

a Description of community — information reflecting the demographic and socio-economic nature of the study area. The following factors were found to provide the most useful information on the populace and activities within a study area: population, population density, average household size, income distribution, and the number, size, and type of establishments within the area (i.e., commercial, industrial, institutional, and agricultural activities).

b Consumer expenditures by household – a generalized inventory of the items that the householders spend money on. The data (derived from Ref. 3) are expressed in terms of the number of consumer items and aggregations thereof. The inventory is "generalized" in that the expenditure patterns of many types of households are included.

c Summary of expenditures – an inventory of the expenditures made in the particular study area being investigated. Data are expressed in terms of dollars spent per unit time on each consumer item separately (i.e., the expenditures for bread, soap, and floor wax are all expressed separately).

d Conversion factors: price per unit amount of item – a listing of multipliers which allow one to convert "dollars spent on bread" to "number of loaves of bread." The unit amounts of each item considered depend upon the nature of the item (i.e., the unit amount of bread is the loaf; for shoes, the pair; and for coffee, the pound).

e Prices of each size and type of item – a list reflecting the retail selling price of consumer items as they are commonly available. The list includes price for all popular sizes and types of each particular item listed (e.g., prices are given for the 1-, 2-, and 3-lb cans of fresh coffee as well as the 1-lb bag).

f Listing of each size and type of item – simply an inventory of the items to be considered in a given application of the model. (The precision of the model's prediction can be varied by expanding or contracting the number of items and sizes and types considered).

g Market coverage of each size and type of item – a listing of indices for each size and type of item, which reflects the share of the total market that any particular size or type commands (e.g., for fresh coffee, the coverage index for 1-lb cans would be much higher than for 1-lb bags, since far more coffee is sold in that form). Market coverage indices are used in the model as "weighting factors" to place emphasis on the most common sizes and types of each item purchased.

h Physical description of each size and type of item – a listing of the amount of material associated with each size and type of item. The amount is actually expressed in terms of 15 different categories of materials, as listed in Table 6. Every common size and type of item is listed separately (e.g., 1-lb cans of coffee are described separately from 1-lb bags). Note that the description covers the item as a whole as it is purchased and therefore includes the packaging material as well as the contents.

i Description of each item's composition by material – a listing of multipliers which convert the number of items purchased to the amounts of material involved on a material-by-material item-by-item basis. Note that this differs from block h in that it looks only at the item as a whole and not at each separate size and type of item marketed. The market coverage indices provide the means for describing what constitutes a "typical" item.

j Inventory of input items – an inventory listing the items which enter households in the study area. Data are expressed in terms of items per week for the area as a whole (not per household). Items are expressed in terms of whatever standard unit amount is most meaningful (i.e., loaves of bread, pairs of shoes, pounds of coffee, etc.).

k Descriptive inventory of inputs to household – an inventory in matrix form which lists each input item, giving both its input amount per unit time and a description of its material composition. This tabulation therefore states how much of each class of material enters the study area's households (i.e., pounds of paper or glass per week, etc.) and also identifies what consumer products were purchased to account for such materials' presence.

l Conversion factors: amount of waste material per item – a listing of conversion factors which state what fractions of the input item are expected to end up as solid wastes, as normally defined (i.e., the conversion factor for a loaf of bread would indicate that 100% of the plastic wrapper and paper label would end up as solid waste, but that only 5 to 10% of the bread would become solid waste, per se).

m. Waste information from other sources – a listing which includes such things as amount of mail and newspapers which enter the study area's households. Such items are more easily and accurately accounted for by this direct approach than on the basis of consumer expenditure patterns.

n Descriptive inventory of potential waste materials and items – a listing of the probable outputs of waste based upon the inventory of household inputs (k) and the conversion factors which state the amount of waste associated with these inputs (l), supplemented by information from other sources (m).

o Distribution factors reflecting waste management practices – a listing of factors which state the manner in which "potential" solid wastes are actually discarded via the principal disposal alternatives.

p Household waste management practices – a series of descriptions of how households of various types within the study area dispose of various types of solid wastes. These practices vary with income level, population density, local ordinances, climate, etc.

q Solid waste generation rates – a series of inventories stating the amount of waste discarded via each of the principal disposal alternatives wherein rates are expressed as pounds of material discarded per unit time or a material-by-material basis.

Block *m* has been included to allow the direct introduction of data on wastes that are best estimated outside the model. Examples of wastes handled this way include: newspapers and periodicals; mail; grocery bags and cartons used to transport groceries; leaves, grass, and garden cuttings; floor sweepings. These wastes are considered separately because their quantities are not dependent upon the household's expenditure on a particular consumer item.* Newspapers and mail are estimated on the basis of information from local publishers and postal authorities; grocery sacks on the basis of national production figures; leaves, grass, garden cuttings, and sweepings on the basis of information concerning population density, income, and the degree to which the study area is built up. To date, we have not been able to develop sufficient information to allow us to make quantitative predictions of how the generation of these materials will vary with given demographic factors, although the experimental studies of waste composition conducted and sponsored by the Bureau of Solid Waste Management should be very useful.

Prediction of Solid Waste Quantity

Block *o* consists of a series of distribution factors that indicate the ultimate fate of solid wastes and reflect the manner in which households typically handle waste materials. These factors indicate the portion of each spent item that will be disposed of via each of the various disposal alternatives. For example, it might state that, from an input of 1 lb of ground coffee, 20 percent of the spent grounds would enter the sanitary sewer (via the sink, presumably), 80 percent of the grounds would be disposed of via the garbage can, and 100 percent of both the metal can and its plastic lid would leave the garbage can. The influence of other local practices, such as whether backyard incineration is permitted, would also be incorporated in this computation. These distribution factors of block *o* are based upon the following: information concerning the waste management practices of various typical types of households (block *p*); information giving the number of households of each such type located in the study area, as given by the community descriptors (block *a*).**

Applying these distribution factors to the inventory of potential wastes (i.e., combining blocks *o* and *n*) yields a series of new tabulations (blocks q, q', q'', q'''), which describe the amount and nature of waste material disposed of via the available disposal alternatives. This final set of tabulations is the end product of the prediction model. Their format is merely a listing of the quantities of wastes generated in the particular study area.

*The amount of newspaper entering a household does seem to depend upon the family's expenditure on newspapers. Actually, the number of copies may correlate well with expenditure, but the fact that the size of newspaper of a given price varies widely precludes estimating the weight of paper consumed. For example, the subscription price for a small-town newspaper may equal that of the *New York Times*. The former constitutes a few pages, the latter, a few pounds.

**Note that, at the present state of the art, only the most rudimentary, qualitative information is available concerning the relationship between measurable socioeconomic/demographic factors (such as block *a*) and the waste management practices of the corresponding households (block *p*). For the purpose of this study, the information of block *q* was developed primarily on the basis of intuitive judgment.

DESIGN OF MODEL AS USED FOR TEST CASE

The primary objective of this study was to develop selected parts of the waste prediction concept into an operable technique and to test its feasibility by applying it to a real community. In the interest of achieving these goals as fully as possible within existing time and funding constraints, it was necessary to assign priorities to those portions of the model that relate to the field data against which it was to be compared.

After several possible alternatives were examined, a study of solid wastes in parts of Jefferson County, Kentucky, was selected for comparison. This study, directed by Professor John Heer at the University of Louisville, was conducted in such a way that residential-household solid wastes were isolated and measured independently of wastes from other sources.[7] Since the primary emphasis in the URS study was in the household-waste-prediction model, it was decided to concentrate on predicting the equivalent waste components.*

The following paragraphs discuss how the particular functions diagrammed in the basic household-solid-waste-prediction model were performed in developing and applying the model for the test case.

Community and Expenditure Data

Data for block *a* of Figure 3 (the description of households in study area) were obtained primarily from Bureau of Census publications. The most important information included the population, the average size of the household unit,** and the general geographical location.†

Data for block *b* (Consumer Expenditures by Household) were obtained from the *Life* study discussed previously. For our purposes, not all the detailed data were of value, since a large portion pertained to expenditures on items that do not contribute significantly to household solid wastes. If the *Life* data are considered as comprising a matrix, the portion drawn upon most heavily by our prototype model related to the following: food, beverages, and tobacco; household supplies; personal care supplies; clothing and accessories; other SRT items. Some 130 consumer items were considered in detail to determine how each contributes to waste generation. The major household characteristic considered in the test case was "geographical region." Expenditure data for the North Central region of the United States were adjusted to reflect the fact that Jefferson County tends to have somewhat larger households than the national average. It was originally intended to consider several income levels independently, but for the reasons discussed on page 20, only the average income for all households was used.

*Examination of University of Louisville's preliminary results indicated LRT items do not contribute significantly to residential waste. For this reason and because of the problems discussed in a previous section, no attempt was made to estimate waste derived from these items.

**The average household size for Jefferson County is 3.42 persons. The national average is 3.36 persons.[8] The conversion factors 3.36/3.42 was applied, to adjust data represented on a national basis.

†The portion of the *Life* study data that applied to the North Central section of the United States (as defined therein) was used in this study.

Material Price and Composition Factors

Data for block *d* (the price/amount conversion factors) were generated with information such as that contained in blocks *e*, *f*, and *g* but did not employ a formalized mathematical model. Rather, information concerning the market coverage and prices of various sizes and types of consumer items were manipulated by hand to obtain price-versus-amount conversion factors. Coverage and price information were obtained from various sources, including production statistics, wholesale and retail trade statistics, and communication with persons employed in the appropriate retail businesses.[6,9] The decision to generate the conversion factors by hand rather than by a mathematical model was made in the interests of maintaining as much flexibility as possible during this developmental stage.*

Block *i* (the description of each item's physical characteristics and material composition) was generated with information such as that contained in blocks *f*, *g*, and *h*. Block *h*, the descriptions of size and type of each item, was developed by actually dissecting several hundred common consumer items and weighing (or otherwise measuring) their respective component parts and materials.

Since the present study is concerned primarily with the development and demonstration of a prediction technique, it was decided to describe wastes in terms of material classifications (Table 5).** The particular classifications (and aggregations) used were selected to allow the model's predictions to be compared with measured waste generation data from the University of Louisville study. The result of this item-by-item analysis is a large and rather comprehensive tabulation of characteristics (block *i*).

Data for block *l* (the waste/item conversion factors) were developed entirely on the basis of personal experience, rather than from specific data sources. The purpose of including these factors is to provide a means of accounting for the fact that many items are purchased in one form but discarded in a very different form. For example firewood is converted to ashes, fertilizer to garden cuttings, and clothing to lint and rags.

Table 5. Material classifications by which wastes are described in prototype model

Combustible materials	
	Paper and cardboard
	Plastics
	Rubber
	Textiles
	Leather
	Wood
	Leaves and grass
	Other combustibles (excluding garbage)
Food-derived garbage	
Metals	
	Ferrous metals
	Aluminum and its alloys
	Copper and its alloys
	Other metals
Glass	
Refractory materials (excluding glass)	

Extraneous Input Information

Block *m* (the mechanism for introducing extraneous information to supplement the model) was most valuable in accounting for the following newspapers and periodicals; mail (excluding periodicals); grocery sacks and other paper bags; and aluminum foil (that amount not elsewhere accounted for); aerosol-type metal cans; miscellaneous plastic bottles (those not elsewhere accounted for); and textile materials. The advantage of handling the first three entries in this manner has already been discussed. The remainder were introduced in this way primarily because they tend to enter the household in association with a great variety of consumer items. This approach, that of using production statistics for the materials themselves, will provide reliable estimates of their rate of consumption by the household, provided the materials are used somewhat uniformly by all classes of households.

In this study, the data for block *o* (the distribution factors to reflect household waste management practices) were developed on an intuitive basis rather than on the basis of blocks *a* and *p*. As mentioned previously, at the present state of the art, sufficiently detailed information is not available for predicting how a household's waste management practices vary relative to measurable demographic and socioeconomic factors.

*Because of their size and complexity, the tabulations of data and results of computations are not included in this report. Copies can be made available to authorized requesters.

**The degree of detail with which items are described should be dictated by the use to which the waste prediction information will be put. Thus, in a comprehensive survey, pursuant to designing systems for waste collection, transport, treatment, and ultimate disposal, it may be necessary to describe all waste constituents in terms of their material composition as well as their physical, chemical, and biological properties. In less than comprehensive studies, it is not necessary to describe wastes in such detail.

For the purpose of this study, however, such a deficiency appears to be of little significance. In order to yield results that could be compared with those from the University of Louisville study (which accounted for the wastes that were found in home garbage cans), the assumption was made that wastes would be distributed throughout the various disposal alternatives in a manner that the investigators assumed was typical, judging from their own experience. It was assumed that virtually all disposable packaging materials, small containers, and paper goods would be placed in the garbage can.* In addition, it was assumed that the fractions of the items that could conceivably be segregated and saved for some other form of disposal (e.g., 15 percent of returnable glass bottles, 75 percent of old clothing, 50 percent of newspapers) would also be discarded via the garbage can. These assumptions are only approximations but must serve until more definitive information becomes available.

The prototype's output takes the form of a series of waste inventories (blocks q, q', q'', *and* q'''), one for each of the major alternative means by which household wastes are disposed of. The format of these inventories is the weight of materials corresponding to each of the material classifications given in Table 5.

*Some of these disposable materials will not be disposed of via the home garbage can. The materials associated with lunches packed in the home but eaten elsewhere are examples of this. In this study, the only materials for which the quantities discarded at home were reduced below the total quantities were wax paper, beverage cans, and "no-deposit, no-return" beverage bottles.

RESULTS OF TEST OF PROTOTYPE MODEL

As indicated in the previous section, the solid waste generation in residential areas of Louisville was estimated to check the feasibility of the waste prediction technique.

The University of Louisville (UL) study involved the periodical collection of the contents of refuse containers from some 144 households throughout the study area. The particular households sampled and the collection schedule employed were both carefully selected to obtain representative samples of residential solid waste. These samples were then assayed to determine both quantity and character, as expressed by a number of physical and chemical indices.

Even though our study and the UL study were both directed toward solid waste generation from households in the same community, certain factors were expected to interfere with their direct comparison. For example, although the UL study considers the same waste items considered in the URS study, it can account for them only if the householder disposes of them via the refuse container. That is, if the householder disposed of the waste in some other fashion (e.g., by separate collection or perhaps on-site composting or burning), it was not counted. Similarly, wastes disposed of by any route other than the common refuse container (e.g., those disposed of via the sink garbage grinder, segregation for salvage, on-site incineration) would not show up in the UL samples. These differences between the two studies are cited primarily to indicate that each method is based upon simplifying assumptions that impose limitations, some of which complicate the task of comparing their respective results.

In many ways Jefferson County was a good test community: it constitutes part of an SMSA,* an area for which a rather large amount of statistical data are readily available; it is neither entirely isolated geographically nor is it submerged within a megalopolis; it has had a reasonably stable population growth pattern and does not, therefore, exhibit some of the difficulties of areas that have "boomed" or are declining in stature.

A primary goal of the UL study was to determine the relationship between a household's income and its waste generation. To accomplish this, the sample households were divided into three income brackets, and waste samples were collected and analyzed to determine the manner in which their amount and content correlated with income level.

The initial plans for this study included a similar goal. It had been intended to take advantage of the fact that our expenditure data include information on the manner in which household consumption patterns vary as a function of income level.[3] It was planned to use this information in our model to develop separate waste predictions for each of three or four income levels. The preliminary results of the UL study indicated, however, that, though waste generation is affected by income level, the statistical correlation between the two was barely significant in the Jefferson County

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*U.S. Department of Commerce has designated Jefferson County, Kentucky, and both Clark and Floyd Counties, Indiana, as the "Louisville, Kentucky-Indiana Standard Metropolitan Statistical Area (SMSA). The principal cities included are Louisville, Kentucky, and New Albany, Indiana.

households considered. For this reason, it was decided not to spend the limited available time and funding on a similar effort. Rather it was decided to develop income-independent predictions.* The basic household consumption information actually selected was that for all nonfarm households in the North Central quadrant of the United States. For the purpose of drawing comparisons, the UL data for all income groups were averaged.

URS Results

As described previously, consumer items were identified as being either SRT or LRT. During the study the waste content of approximately 120 items was determined.** The amount of household waste contributed by each of the purchased items was determined for each of the constituent materials. For example, the amounts of paper, plastic, and aluminum foil attributable to the consumption of two separate items, say breakfast cereal and laundry detergent, were determined and tabulated separately in terms of pounds of waste material per household per week (Table 6).

Block *m* in the model was described earlier as providing a means of incorporating generation data for waste components whose amounts are not closely related to any particular consumer expenditure rate. The final row of entries in Table 6 consists of totals calculated for "block *m*" wastes, such as mail, leaves, grass, garden cuttings, and miscellaneous wastes.†

*This study of expenditure pattern data has led to the conclusion that income level is perhaps the most significant single factor influencing wastes. It is recommended that further studies be directed toward determining the impact of income on waste characteristics.

** The list of items comprising Table 3 was pared down by eliminating LRT items (and the packages for same), items with insignificant residential solid waste content, and those for which the expenditure per household was less than $0.05 per week.

†Based on U.S. Post Office statistics, it was estimated that some 7.1 lb of paper and cardboard per week enter the typical Jefferson County household via the mails.[10,11] On the basis of preliminary figures obtained from Bureau of Solid Waste Management, it is estimated that some 1.7 lb per household per week of yard wastes and 1.1 lb per household per week of waste wood from various sources are to be expected. Circulation information and newsprint usage estimates were provided by the publisher of Louisville's principal newspapers.[12]

University of Louisville Study Results

Because each of the households in the UL study was sampled several times during the study period, the observed waste generation data were expressed in terms of a statistical distribution (Table 7 and Figure 4).

The UL results also differed in format from ours. They segregated waste materials into 5 categories (consumer items in Figure 4), whereas the present study employed 15 material categories. The relationship between the two systems has been indicated (Table 8). The lack of conflict between the two systems stems from the fact that we were aware of their format and designed ours to be merely an expansion of it. The expanded format is, of course, desirable in that it provides the degree of flexibility necessary to make the data applicable to a wide range of uses.

Comparison of Studies

The waste generation rates of Table 6 have been summed into five categories (see Table 8), which correspond to those in the UL report, and are listed in Table 7. Those summations estimated in this study have been plotted as bold dots in Figure 5 to allow comparison with the UL results. Note that each of the predicted values is smaller than the corresponding value measured by UL. This would be expected, since none of the predictions are complete to date (i.e., for each, there are items that have not yet been fully accounted for).

We believe that the performance of the prototype computation is satisfactory. The discrepancies between the URS study and the sampling study are well within the expectation for this preliminary trial of a novel technique. Furthermore, the discrepancies are explained by the fact that the present model is based upon only a minimum amount of information. It was stated previously that the prototype model used for the comparison study considers only SRT items and packaging materials and excludes LRT items. It is believed that, given the opportunity to include these and other excluded items and to refine various other preliminary estimates and approximations, the waste generation rates predicted by the model would progressively approach the actual average rates.‡

‡The actual average rates are not necessarily equal to those measured since measurement techniques usually suffer from sampling and other errors.

Table 6. Prediction of waste generation rates by material and origin*

Consumer items	Paper and cardboard	Plastics	Rubber	Textiles	Leather	Wood	Leaves and grass	Other combustibles	Food-derived garbage	Ferrous metals	Aluminum and its alloys	Copper and its alloys	Other metals	Glass	Refractory materials	
	Categories of waste materials															
Food, beverages, and tobacco	1.49	0.15							†	2.04	0.12			3.30		
Household Supplies	0.62	0.05	†	†						0.13	†			†		
Personal care supplies	0.42	†		Not a significant amount of waste						0.04	†			0.93		
Clothing and accessories			†	1.00	†											
Wastes from other sources (block m)	16.33	0.11		0.46		1.10	1.70			0.15	0.06					
Total	18.86	0.31		1.46		1.10	1.70			2.36	0.18			4.23		
	23.43								0	2.54				4.23	0	30.20

*Many of the spaces in Table 6 are simply shaded grey. This designates that the amount of waste material so identified is "not significant" relative to the total amount of solid waste generated. The daggers appearing in Table 6 signify values that we feel to be significant waste constituents but for which we have not been able to obtain complete information to allow prediction. For example, "food-derived garbage" is a category that is surely significant. We are not, however, presently able to predict with accuracy the rate at which this material is produced. This category of waste may perhaps be best estimated on the basis of direct measurements.

†Present data are not complete and hence do not warrant tabulation.

Table 7. Comparison of waste generation rates (lb/HOUSEHOLD/wk)

Material	Measured by Univ. of Louisville study			Estimated by URS prototype model
	Low	Medium	High	
Paper	24.9	29.7	37.8	23.43
Garbage	4.8	9.9	12.6	Not estimated
Glass	3.8	5.3	6.7	2.54
Metal	3.9	4.7	6.0	4.23
Minerals	0	0.7	3.1	Not estimated

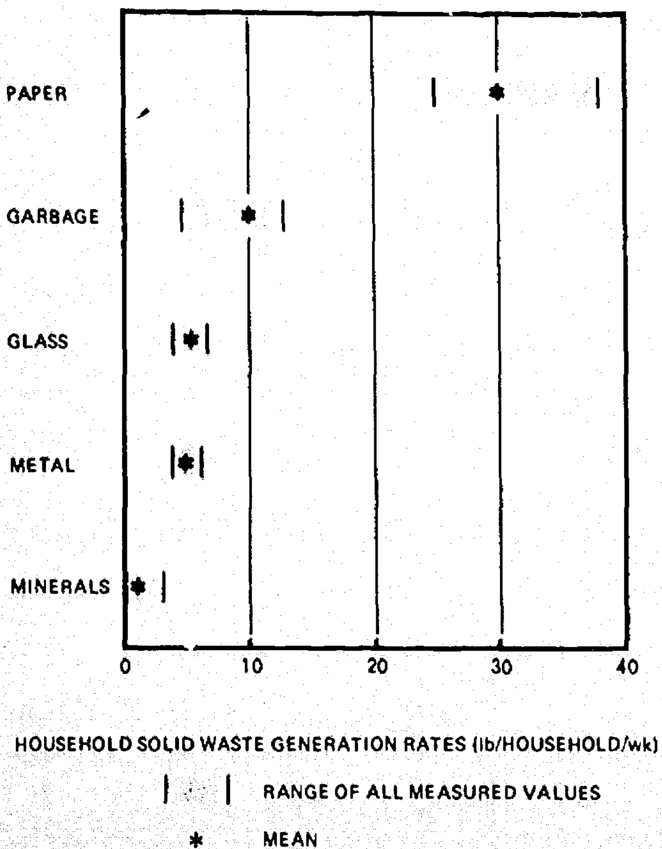

Figure 4. Solid waste generation rates observed by University of Louisville sampling study.

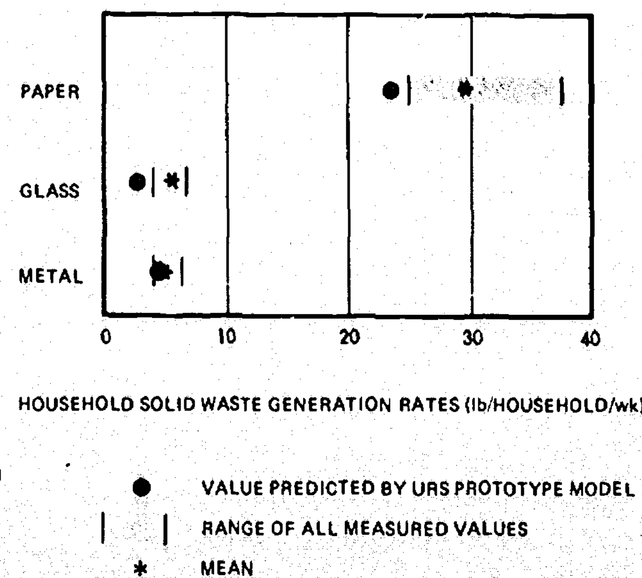

Figure 5. Solid waste generation rates predicted by using URS prototype. URS results are superimposed over University of Louisville results.

Table 8. Comparison of output data formats

University of Louisville waste categories	URS prototype waste categories
Paper	Paper and cardboard
	Plastics
	Rubber
	Textiles
	Leather
	Wood
	Leaves and grass
	Other combustibles (excluding garbage)
Garbage	Food–derived garbage
Metal	Ferrous metals
	Aluminum and its alloys
	Copper and its alloys
	Other Metals
Glass	Glass
Minerals	Refractory materials (excluding glass)

CONCLUSIONS AND RECOMMENDATIONS

The solid waste prediction method investigated in this project is technically feasible and appears to offer a unique and effective means of estimating waste quantities and characteristics. In addition, it provides a framework for the prediction of future wastes. Table 9 indicates the relation of the progress to date (phase 1) to the overall requirements of the program and suggests that subsequent work be undertaken in two phases. Phase 2, the next logical step, would be devoted to completing the capability to predict the solid wastes from residential, commercial, and institutional activities in the community. These wastes make up a large fraction of the solid wastes arriving at disposal sites and are very susceptible to changes (as a result of changing technology) that affect waste-handling and disposal operations. Moreover, pertinent input data are generally available concerning these wastes. For these reasons, it appears desirable to give priority to these aspects of the work. In phase 2, however, the problems of predicting solid wastes from industrial, agricultural, and other sources would also be investigated, at least through the stage of a test of the approaches. The major and final development of prediction methods for wastes from these sources would constitute the third phase of the work. There are two reasons for relegating these to phase 3. First, current work (being done by other contractors) as well as planned studies concerning industrial and agricultural wastes should be used as a basis for the proposed prediction methods. The results will not be available to an appreciable extent during the phase 2 period. Second, the requirements for a computerized solid waste estimation procedure for industrial, agricultural, and possibly other wastes have not been defined or delineated. Both of these deficiencies would be resolved by the preliminary studies in phase 2, and decisions concerning the need for phase 3 and specific approaches to be taken therein would thereby be permitted.

The major tasks that should be undertaken in phase 2 are the following:

1. Complete the development of the residential-household-waste-generation model, including those aspects related to LRT items and the prediction of future wastes.
2. Adapt the model to handle the wastes generated by commercial, institutional, and other activities that are found to be major contributors.
3. Perform preliminary model design and conduct a feasibility study for prediction of industrial, agricultural, and other wastes.
4. Establish computation specifications; reevaluate preliminary residential model; relate desired model specifications to computer capacity and operating cost; firm up computer model specifications; establish input, output, and function formats.
5. Develop computer program; prepare flow diagrams and design overall program; prepare and debug programs; verify running times.
6. Expand standard data banks; collect, evaluate, and collate as many standard activity and commodity descriptions as are pertinent to the test area (see task 7); put data in computer format.

Table 9. Prediction method status and proposed work

Waste types	Development stages					
	Conceptual design	Preliminary data collection	Manual test	Final design program for computer	Complete data collection	Computer test
Residential, SRT Residential, LRT * Residential, future		Phase 1 (completed)				
Commercial Institutional				Phase 2		
Industrial						
Agricultural					Phase 3	
Other						

*SRT–short-residence-time items
LRT–long-residence-time items

7. Select test area; develop test area data; collect, evaluate, and compile input commodity and activities inventories and schedules for area, including population, land use, and other changes; put data in computer format.

8. Run waste prediction for test area; compute several pertinent predictions for a range of conditions.

9. Evaluate results; compare predictions with independent estimates or surveys; prepare report.

REFERENCES*

1. Office of Statistical Standards, U.S. Bureau of the Budget. Standard industrial classification manual, 1967. Rev. ed. Washington, D.C., 1967. 615 p.

2. Urban Renewal Administration, Housing and Home Finance Agency, and Bureau of Public Roads, U.S. Department of Commerce. Standard land use coding manual. 1st ed. Washington, U.S. Government Printing Office, 1965. 111 p.

3. Linden, F., *ed.* Expenditure patterns of the American family. New York, National Industrial Conference Board, 1966. 175 p.

4. Sindlinger and Company, Inc. 1967 brand inventory of household durables in Delaware Valley, U.S.A. Philadelphia Inquirer, June 1967. 30 p.

5. Automobile Manufacturers Association. 1968 automobile facts and figures. [Detroit], 1968. 70 p.

6. Personal communication. T. Healy, Safeway Stores, Inc., to G. B. Boyd, URS Research Company, July 1968.

7. University of Louisville. Louisville, Ky. -Ind. metropolitan region solid waste disposal study; interim report on a solid waste demonstration project; volume I: Jefferson County, Kentucky. [Cincinnati], U.S. Department of Health, Education, and Welfare, 1970. 205 p.

8. Sales management's survey of buying power. *Sales Management*, 98 (12): 1, 3, 5 ... 15, June 10, 1967.

9. Bureau of Census, U.S. Department of Commerce. Special report on household ownership and purchases of automobiles and selected household durables, 1960-1967. Current Population Reports Series P-65: Consumer Buying Indicators, No. 18. Washington, U.S. Government Printing Office, Aug. 11, 1967. 24 p.

*Perhaps one of the most valuable results of performing the present study was the collection and evaluation of a large body of statistical information concerning community inputs and activities. More specifically, this information consists of industrial and agricultural production rates, commercial sales activity, personal consumption patterns, and the like. Whereas the amount and detail of information are not readily describable, some feeling may be obtained by considering that more than 200 documents constitute the basic bibliography (all of these contain information that has direct bearing on predicting waste generation). For simplicity, however, only those sources of information that precisely document the text of this report have been cited herein.

10. Personal communication. B. Ehrler, Postmaster, Louisville, Ky., to G. B. Boyd, URS Research Company, Oct. 1968.

11. Personal communication. R. R. Germain, U.S. Post Office Department, San Francisco, to G. B. Boyd, URS Research Company, July 1968.

12. Personal communication. L. A. Kern, Traffic Manager, Louisville Times and Courier-Journal, to G. B. Boyd, URS Research Company, July 1968.

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