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**Regional Solid Waste
Management:
An Empirical Approach**

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University of California at Berkeley

REGIONAL SOLID WASTE MANAGEMENT
AN EMPIRICAL APPROACH

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PREFACE

This paper describes the rationale and methodology applied by the Economics and Planning team as part of the comprehensive studies on Solid Waste Management conducted by an inter-disciplinary group involving Economics, Planning, Operations Research, Engineering and Public Health, at the University of California (Berkeley and Davis).

The present discussion refers to the initial phases of work that are being carried on during the last two years. Efforts are under way to launch new phases of Waste Management on a continuing basis.

I am grateful to Dr. C. G. Golueke, Research Co-ordinator of the Comprehensive Studies on Solid Waste Management, Sanitary Engineering Research Lab., University of California, for kindly reviewing earlier draft versions of this report. My thanks are also due to Mrs. Barbara Litchfield for typing this manuscript.

S. Ananda Rao

REGIONAL SOLID WASTE MANAGEMENT
AN EMPIRICAL APPROACH

By

S. Ananda Rao*

INTRODUCTION

Background

The affluence of modern civilized life has produced both "what is needed by society" and what is discarded as "waste" in the course of everyday life. Changes in consumption and production practices over long time intervals have significantly affected the nature of the wastes, and have challenged the available body of technology for efficient disposal.

Inadequacies of presently available technology are not the only factors contributing to the solid waste problem as it now exists. A problem, perhaps the gravest of all, is found in the unrealistic approaches to waste management as it is practiced today. Solid Waste Management problems facing vast metropolitan and nonmetropolitan regions have reached crisis and near-crisis points in various communities (e.g., the recent San Francisco-Brisbane rubbish feud), and the need for an overall, effective, and regional approach to Waste Management problems is emphasized and analyzed by various interested private and public bodies. The passage of The Solid Waste Disposal Act 1965 gave impetus for intensive research in this field of public concern, so that the various public bodies (local, state, and interstate) charged with the responsibility for waste disposal could be better equipped to provide technical guidance in the planning, development, and conduct of solid waste disposal programs.

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As a recipient of a two-year research grant from the U. S. Public Health Service in early 1966, the University of California at Berkeley has launched a multidiscipline, multicampus study of the problems relating to the various facets of solid waste problems among which are public health, economics, planning, operation research, sanitary and other branches of engineering.

The long term objectives of the research team is to approach a series of principal objectives essentially sequentially and at the same time recognizing the degree of overlapping as and when it was felt necessary. The primary objectives (or aims of pursuit) of the planning team are as follows:

- (i) Formulation of necessary mathematical models for studying the structure and relationships between different types of solid waste generated and relevant variables describing economic, demographic and land use information.
- (ii) Development of consistent and comparable data on quantity and types of solid wastes generated and allied economic information through formation of disposal service areas.
- (iii) Implications of solid waste generation for present and future land use planning from a regional approach.
- (iv) Incorporation of technological changes in transportation and disposal of solid wastes into the study of land use planning.
- (v) Implication of changes in methods of transfer and disposal of solid wastes on private and public expenditure, jurisdictional conflicts and public interest.
- (vi) Implications of changes in current methods--the phase of actual implementation or actual adoption of substantive recommendations emerging from the empirical portion of the research project.

The above objectives form a set of principal components of a comprehensive plan for pursuing the different facets of research relating to the economics and land use planning aspects of solid wastes management. In this paper, the first three aspects are discussed.

After briefly outlining the technological and jurisdictional problems involved, the present paper describes the economic and planning aspects of a regional approach to solving solid waste problems. The San Francisco Bay Area is used as an illustration, inasmuch as the approach could be applied very usefully to the solution of other area's problems.

Finally, this paper describes the method of approach for analyzing regional solid waste management problems. Many facets of work are still in progress and the body of data being used in the study are not yet ready for presentation and as such they are not given in this paper. Only illustrative lists of sites and tentative definitions of functional boundaries are given. The final sets of data and maps used in the study would be furnished to interested readers in the future.

future It is planned to report additional work done on this subject during meetings of the WRSA.

Factors Complicating the Solid Wastes Problem

Solid waste is inherently integrated into the total problem of air and liquid waste pollution. Thus, the burning of solid wastes may increase air pollution, while the use of garbage grinders necessarily increases the load on the liquid waste disposal system. On the other hand, measures undertaken to abate the air pollution problem or to decrease the output of liquid wastes usually result in an increase in the quantity of solid waste that must be handled. The generation of solid refuse is not only a function of the existence of households and municipalities, it is a consequence of all productive processes. Business, industry, and agriculture all generate solid wastes.

As more convenience foods are produced, one can see a definite increase in the amounts of agricultural waste left either in the fields or disposed of by the processing plants. The net effect of this change is the imposition of an increasingly greater burden on waste disposal facilities of

the production and of the consumption segments of society. One aspect of the problem is the shift in the location of waste disposal sites and a possible change in the demand for the existing waste disposal facilities and methods. The ultimate impact on costs of disposal is not clear, but some or all of the costs may be transferred to the consumer in the form of higher prices.

While there has been a constant change in the amounts and types of solid wastes generated by the several segments of society, the physical and technical ability to cope with the problem is growing at a less than desired rate. This is due to a combination of several factors, important among which are the dwindling supply of available land for the most commonly accepted method of disposal, namely, sanitary landfill, and a somewhat slow rate of development and acceptance of alternative methods of ultimate disposal. The handling of wastes itself is sometimes haphazard, and the collection, transfer, and disposal functions must become part of an overall analysis before lasting solutions can be found.

The State of Technology of Disposal Methods. Some idea of the limitations of present-day technology for treating wastes can be gained from a description of the conventional methods of waste disposal. The basic methods, disregarding many environmental differences, are sanitary landfill, incineration, composting, and disposal at sea.

The practice of composting has been and is limited because of the combination of a conviction that the compost product should be a saleable product and a virtually nonexistent market. However, the use of compost has possibilities in the future for extensive application on land to improve land quality and thus eventually increase land values to a degree at which they would more than offset the cost of producing the compost.

Although incineration has been practiced extensively, high operating costs and the persistent raising of air pollution standards have been influential in reducing the extent of its usage. Incineration in effect transforms a portion of the solid wastes into gaseous wastes and does indeed reduce the original volume. Nevertheless, a considerable portion of the waste is left as residue ash and noncombustible material. The method is an economically efficient one for the disposal of a large portion of solid waste material, provided it is operated under economies of scale, and the by-products of its operation, viz., heat and gas, are effectively converted into useful resources.

Only the organic fraction of refuse, i.e., from 50% to 60% of the total production of solid wastes, is subject to composting and incineration. The weight of the organic refuse introduced into a compost operation is reduced by 30% to 60%, and as much as 80% to 85% in an incinerator. That fraction of the solid wastes not amenable to incineration and to composting, the ash remaining after incineration, and unmarketable compost produced in composting, all must be disposed of by some method other than incineration and composting.

At present the most widely practiced method of complete disposal is the sanitary landfill method. It has been developed to a degree suitable to the esthetic and health requirements of each area. Unfortunately, urban sprawl has reduced the amount of land available for fill, and is driving up acquisition costs to a point at which land fill no longer is the least-cost method of disposal.

Disposal at sea presently is confined almost entirely to the dumping of radioactive wastes. In the Bay Area, some cannery wastes are disposed in this manner. In former years, much of the municipal refuse produced in coastal areas was barged to sea and dumped indiscriminately, and invariably portions of these dumpings floated back to the shore. This caused a public reaction and resulted in the discontinuance of this method on any substantial scale anywhere in the United States. Some day disposal at sea may become an effective and acceptable method, provided the solid wastes are processed such that they will sink in the ocean and remain submerged [3].

Other disposal methods currently in practice or as yet in the experimental stage are: (1) grinding garbage for transport to and treatment in existing sewage treatment facilities; (2) swine feeding; (3) wet oxidation; (4) pyrolyzation; (5) aerobic digestion; and (6) anaerobic digestion. The last four named methods are as yet in the experimental stage from the standpoint of applicability to solving the waste disposal problems. With the exception of swine feeding, these methods are undergoing a thorough investigation as a part of our overall continuing research on solid wastes management.

Fragmented Political Jurisdictional Approach.---Generally, solid waste disposal has been and is based upon a fragmented jurisdictional approach. Each political entity bases its waste disposal method on inherited operational procedures or on methods that are the result of hasty decisions

made for solving a pressing disposal problem. Unfortunately, the latter methods generally provide only temporary or, at most, short range solutions to the problem. Since at its source, solid waste is of negative utility, the modus operandum has been to provide at the least possible direct cost, a method of disposal that would satisfy the immediate requirements for health and esthetic standards.

As stated previously, waste handling generally has become a function of a haphazard combination of public and private sectors. While this need not be a noticeable deterrent to efficient waste disposal operation, it has in fact reduced the efficiency of current waste management both economically and esthetically. This condition, along with the existence of a large number of fragmented local jurisdictions, has compounded the problems of waste management. As each local government attempts to dispose of the solid wastes within its political jurisdiction, the criteria for making its decisions are necessarily based on a noticeably small number of alternative (technically feasible) solutions. This further has the effect of limiting the economies and enhancing the diseconomies that result from small-scale operation. Thus, the constraint of fragmented political jurisdictional approach can serve only as a deterrent to effective waste management practices.

The problems described above, together with the inability of individual areas to absorb their own wastes because of limitations of present technology, plus an unrelenting increase in volume and constant change in composition of solid wastes, all combine to render too complex the management of solid wastes within traditional political boundaries. Effective comprehensive planning of solid waste management therefore becomes a problem at large and should be treated accordingly with a full-scale study of the impact of any proposed solutions on the entire community with respect to its population, employment, land use, and the like. Moreover, the problem of handling and transfer of solid wastes should be examined with a view to achieving an optimum transportation plan consistent with proposed disposal methods.

In concluding the introductory statements, it should be said that the existing state of technology with regard to disposal methods, the fragmented political jurisdictional approach and its attendant disadvantages, the complexities of the sources generating wastes, all point toward the need for a fresh approach, be it named "effective" or "overall" or "regional" in character.

The complexities themselves suggest heuristically that a regional or subregional approach to waste management practices which transcends the political jurisdictions can come to grips with the real problem and can lead to long-lasting solutions that are both efficient and satisfactory to the community at large.

Need for a Regional Model

Before a system for disposal of solid waste can be devised, it is necessary to know accurate information concerning the quantity, source, composition, distribution, and variability of solid wastes. The source should be identified under categories such as "households," "type of commercial, industrial, and agricultural activities," and other appropriate categories of generators of waste. For decisions regarding the feasibility of disposal methods, composition of wastes must be further distinguished by type (garbage, rubbish, street refuse, etc.) and by physical and chemical properties (caloric value, nitrogen content, etc.). In addition, the need exists for estimating significant relationships that explain the amount and types of waste generated in a given region based on comparable data relating to waste generation and specific waste generators. In order to specify the various data requirements in detail and to formulate the specific relationships to be estimated, it is necessary to devise a model-building framework that is conceptually sound and at the same time operationally feasible for a given region.

The rationale underlying the model-building approach is the development of alternatives and of an optimum solution to the regional solid waste management problem which is based on factual data. Since standards of solid wastes management depend on criteria based on esthetic values, public health requirements as well as on economic efficiency, it is necessary that these constraints be effectively recognized within the model. With an awareness of such social and political aspects, alternative solutions to the problem are developed with the aim of making it possible to select an optimization program. In addition, in order to develop a model which encompasses all of the characteristics and interrelationships that are involved in a regional solid waste management system, it is necessary to specify all of the variables and their implications in an analytical model framework applicable to any given region.

The need also arises to develop a method for determining what changes in the characteristics of waste will result from corresponding changes in the related variables. A possible approach to this problem is an a priori rationale of comparisons with past qualitative changes resulting from changes in associated variables. Additionally, an inquiry into technological progress with respect to containers and associated waste producing products will clarify the expected changes in composition that might result from this progress.

A REGIONAL MODEL

Framework and Scope

The mathematical framework of the model envisaged in this paper consists of multiple regression analyses. Differences in future development of a given region will have both qualitative and quantitative impact on future volumes of solid waste. The method used to aggregate or eliminate the related variables will be highly instrumental in discerning these differences. In this model the aggregation of variables will be governed by data availability. The extent of the interrelationships existing between the variables will be determined on a spatial basis and then projected to a future period utilizing the basic economic growth projections for the area (e.g. the result of the Bay Area Simulation Studies).

The plan is to define each category of waste in terms of its related variables, so that whatever the extent of growth in an area, the waste may be estimated. Once this level of analysis is reached it will become necessary to explain the impact of any designed system of disposal on the region in terms of its social, economic, and political characteristics. Every method of waste disposal will have significant but different implications for the area and these must and are being analyzed in the research project.

Objectives

There are two principal objectives of the waste generation model. The first is to develop a comprehensive, factual basis for the quantitative aspects of the regional solid waste problem by giving due consideration to

the spatial and functional nature of the problem. The second is to use this factual base as the primary source of data in analyzing and estimating future volumes of solid waste.

The ultimate goal of the analysis is to provide any given region with generalized methods of approach for arriving at a solution to the solid waste problems within its functional boundaries. While it is possible to develop a theoretical framework with very little practical significance, the need today is to incorporate many of the systems analysis techniques into a comprehensive model that will give solutions capable of testing against the levels of data that are presently available. Traditional methods of recording data on amounts and types of solid waste generated by the scavenger companies thus far have precluded a thorough analysis based purely on theoretical grounds. By necessity, the method at present should conform to the available body of data. A systems analysis approach based on existing data will facilitate a more thorough understanding of the solid waste management problem than heretofore possible and will provide insights into the economic, social, and political aspects of the problem which hitherto have been considered only on the periphery.

Study Region

To test the validity of the model, an area of presently fragmented jurisdictions has been chosen which encompasses all of the complexities of the waste problem. Because of its nature and proximity, the nine county San Francisco Bay Area region was selected as the operational area. The planned approach is to collect and correlate data on the types and quantities of waste generated in the Bay Area, along with data on the waste generators, and attempt to explain the interrelationships among them.

Approach

Definition of Solid Wastes: Source and Composition Relationships.

--Before actually specifying the relevant variables in the model framework, a note is in order concerning the interrelationships between sources (or origins) of solid waste and the composition (or type).

The American Public Works Association has classified municipal

refuse into the following:[1]*

- Garbage
- Rubbish (combustible and noncombustible)
- Ashes
- Street Refuse
- Dead Animals
- Abandoned Vehicles
- Industrial Wastes
- Demolition Wastes
- Construction Wastes
- Special Wastes
- Sewage Treatment Residue
- Agricultural Wastes (by omission).

To facilitate the selection of a disposal method, a broad classification may be used in which a given category may include two or more of the AFWA groups. For example, in planning an operation in which incineration will be the disposal method, refuse is often grouped simply into garbage, combustible refuse, and non-combustible refuse. Where sanitary landfill is the principal method of disposal, the classification may be made into compactible and bulky wastes. Composting requires that the lines be drawn according to materials suitable for the process, which in turn depends upon the method of composting that is being used. For specific types of studies, the division may also be made into urban, rural, and industrial wastes.

Once refuse has been classified by composition and source, correlations can be made between the two. A listing of the interrelationships is necessary to serve as the base for the establishment of the relevant independent variables of waste generation. These classifications can be further disaggregated; e.g., "households" can be considered separately as a single family, multiple family, or group quarters, and the production of "rubbish" from each of these units can be further broken down into paper, ferrous metals, nonferrous metals, glass, etc.**

Specification of Variables.--Waste generation is a consequence of a variety of economic, geographic, and demographic factors. Each category of waste may be associated with one or more explanatory variables. The major

*Numbers in parenthesis refer to the Bibliography given at the end of the text.

**For purposes of brevity all of the possible relationships are not listed in this paper.

variables explaining waste generation are population, income, employment, and land use. These parameters, along with less significant variables, will be used to develop cross-correlations that will identify their relationships to the various categories of waste and thereby facilitate effective projections of solid waste volume.

In an ideal analytical model, every conceivable interrelationship between the sources and types of waste, and the activities that might affect the generation of the waste would be set forth and tested. While cost constraints and data limitations dictate that the actual dimensions of the model may be less than ideal, the establishment of relevant relationships should be as complete as possible. A particular case study may aggregate the relationships to data needs but the theoretical formulation should be available for a more detailed analysis as additional data on solid waste are developed.

As a starting point in the selection of variables, it is useful to consider those variables which have been found significant in other studies.

In the Aerojet-General Corporation's study on waste management, the observation is made that:

"Urban refuse, like almost all waste, varies considerably from area to area, depending primarily on the time of year, the affluence of the neighborhood, and the ratio of apartments to homes. Urban refuse can also change as new products are developed, as evidenced by the recent increases in plastics and metal foils, although such changes in the past have been slow to develop." [2]

Another evaluation of significant variables appears in the study of the Detroit Metropolitan Region. It is stated that:

"In arriving at an estimated quantity from municipalities, where records were not kept or were not complete, heavy reliance was made on the data from other municipalities and adjusting factors, such as lot size, inhabitants per household, economic status, ratio of residential to commercial (activities) and method of disposal available." [3]

In a technical report [4] published by the Sanitary Engineering Research Laboratory of the University of California (Berkeley), a number of influencing factors on collection systems are discussed which affect the amount of refuse collected. For example, physical conditions are listed as one set of variables. Under this heading are climate and population density, both of which exert an influence on the regularity of collection service, and thereby ultimately on the amount of refuse introduced into the system for disposal. The report also points out that the important characteristics

of the population are social and economic in nature and govern the amount and composition of solid waste that enters the disposal system.

A list of variables which might be significant in influencing quantities of various types of solid wastes by source is given in Table A. All of the variables listed in the table need not be used separately in any study. As mentioned previously, data limitations may make necessary the aggregation of certain variables. The final selection ultimately depends both on the structure of the model and on the reliability of the data being used.

Definition of Functional Regions (Disposal Service Areas).--In order to develop data on solid waste and related variables on a uniform basis, it is necessary to define a set of functional geographic units into which the region being studied, i.e., the nine-county San Francisco Bay Area, could be divided. Since this division is instrumental in explaining the interrelationships between several variables, it is desirable to choose the smallest geographic unit so that a large number of independent observations can be developed for the application of the multiple regression technique.

The 1960 Census tracts are used as primary units for the purposes of many empirical studies, since they provide an initial data base for building up various economic data such as population, employment, and land use. However, while data on demographic and economic elements are available by Census tracts, the corresponding data on solid waste generation is conspicuously absent for such a small geographic unit. It would have been ideal if solid waste data had also been available by Census tract, since such a situation would have provided 750 or more observations for the San Francisco Bay Area Study--a statistician's dream for multiple regression analysis.

Since use of Census tracts as primary geographical functional units for waste disposal was pre-empted because of the paucity of solid waste data, a larger unit consisting of groups of Census tracts (or parts thereof) was considered as the primary functional boundaries for analysis. Consequently, the available data on explanatory variables such as population, employment, and land use had to be aggregated spatially to correspond to the larger regions defined as the primary functional boundaries. These primary functional boundaries, designated in this study as "Disposal Service Areas" (D. S. A.), form the basis for developing comparable data on all variables, and make possible a sufficient number of observations for the analytical portion of the model described in the previous section. The D.S.A., as defined in this

Table A

SOURCES AND THE VARIABLES SIGNIFICANT IN DETERMINING
THE QUANTITY OF WASTE PRODUCTION

Source of Waste	Function of
Household	<u>Population</u> <u>Number of Households</u> <u>Income</u> <u>Land Use:</u> Lot size, intensity of use and apt. to single family ratio Time of year Collection rates Frequency of collection
Agricultural	<u>Land Use,</u> including intensity of use Time of year Internal method of disposal
Extractive	Nature and extent of activity
Manufacturing	Nature of activity <u>Size:</u> Employment level and/or quantity of output Salvage values Internal methods of disposal
Commercial and services	<u>Size:</u> Employment and nature of activity
Special waste:	
Municipal:	<u>Population</u>
Street refuse	Number of streets Socio-economic characteristics of area
Park and other public areas	Number, size, and nature of use
Sewage residue	<u>Population</u> Method of treatment
Abandoned vehicles	Number of vehicles Distribution by age Legal restrictions
Demolition and construction	Number of new buildings Size of new buildings Type of material/construction Renewal projects Highway building, BART, etc.

study, transcends all political boundaries (city or county) and establishes functional boundaries. This definition serves the purpose of establishing mathematical relations among waste generation and other variables.

The definition of an individual D.S.A. is a nebulous one as are all functional boundaries. The definition of D.S.A. must be brought up to date if and when there is a change in the nature of the function it represents.

DATA ON SOLID WASTES, POPULATION, EMPLOYMENT, LAND USE, AND INCOME-- DEVELOPMENT OF DATA AND CURRENT STATUS

Location and Identification of Disposal Sites.--Prior to the use of the concept of the functional boundary described above, the first data requirement was the location and identification of all of the solid waste disposal sites. Using information obtained from the California State Department of Public Health, and that gleaned from such studies and reports as The Refuse Disposal Needs Study [5] by the American Association of Bay Area Governments, The Refuse Disposal Study for the Sanitary Fill Company [6] by Wilsey, Ham, and Blair, The Future of San Francisco Bay [7] by Mel Scott, a complete list of all Bay Area Disposal Sites was obtained. A tentative* listing of all sites which were operational within the study period was made. (See Table 1 of Appendix A). The sites were then located on county Census tract maps.

In some cases, the nature of the sites was such as to make impossible any realistic estimate of the amounts of waste in a given site. By eliminating these sites, the boundary problems were simplified without endangering the generality of the procedure.

Division of Study Region into Functional Regions (D.S.A.s).-- Following the location of the disposal sites, the next step was to define the disposal service areas into which the study region could be divided for developing the primary data elements. The actual drawing of boundary lines for each D.S.A. was done as follows: If a disposal site received waste generated from one or more Census tracts (or parts thereof), that region was defined as a disposal service area. In situations in which two or

*The tentative list is being brought up to date in consultation with the California Department of Public Health (Pete Rogers and his staff).

more disposal sites receive waste from two or more overlapping Census tracts, and it was impossible to split the Census tracts meaningfully, a single disposal service area was defined to consist of that total area. In other cases, the Census tracts were split between different disposal service areas since it was possible to identify these parcels. Thus the amount of waste deposited in the site (sites) is always made comparable to the waste generators with reference to the functional boundary (or D.S.A.) as the basis ---- eliminating any arbitrary splicing of boundaries. For the purpose of this study it was possible to divide the entire nine-county San Francisco Bay Area into 31 functional boundaries. (See Table 2 and 3 in Appendix A).

Problems encountered in defining disposal service areas for the nine Bay Area counties generally stemmed from two primary sources.

The first source was the multiple county use of a particular disposal site. This practice necessitated the formation of "cross-county" D.S.A.s. The following are examples of cross-county D.S.A. problems (see Table 3 in Appendix A for a precise identification): Southern Marin County exports some of its solid waste to Contra Costa County for disposal in the Western Contra Costa dump. The wastes include all of the household garbage and refuse as well as most of the commercial and industrial waste generated in southern Marin County. One Census tract in Contra Costa County exports its household garbage and rubbish to Solano County for disposal in the Benicia dump. All of the solid waste from the Vallejo District, which encompasses eighteen census tracts, is exported to Napa County's American Canyon Disposal Site. The southern portion of San Mateo County exports its household, commercial, and much of its industrial waste into Santa Clara County.

The second problem encountered in defining the different D.S.A.s was that of splitting Census tracts to correspond to collection boundaries in situations in which scavenger company collection routes did not coincide with Census tract boundaries. The following are specific cases: In Marin County Census Tract G-28 was divided between western Marin D.S.A. No. 1 and Contra Costa D.S.A. No. 1, following the boundaries of the Tamalpais Community Service District. Census Tract No. 65 in San Mateo County was divided between the incorporated and unincorporated sections of the tract. The incorporated section was located in central San Mateo D.S.A. No. 4,

and the unincorporated section in the Los Altos D.S.A. No. 6 of Santa Clara County. Santa Clara County Census Tract No. J-68 was divided into three separate parts. Two parts were located in the Los Gatos D.S.A. No. 5, and the remaining portion was located in San Jose D.S.A. No. 7. Census Tract No. M-91 of Santa Clara County was divided with one portion going to Mountain View D.S.A. No. 2, and the other section to Sunnyvale D.S.A. No. 3. The remaining split occurred in Sonoma County where Census Tract No. C was divided along Eastwood Road and Highway 101. The Southern or Windsor section of the tract went into Santa Rosa D.S.A. No. 2, with the remainder going to Healdsburg D.S.A. No. 1. With regard to Napa County, only one D.S.A. was defined, since splitting of Census tracts could not be resolved meaningfully because of the overlapping of franchise areas within the Census tracts. For the present San Francisco county is treated as a single D.S.A. It might be possible to divide San Francisco county into ten or twelve D.S.A.s when more detailed data become available.

After defining the set of functional boundaries, a systematic approach to data collection was required to maintain the standards of consistency, reliability, and comparability. The approach was formulated after considerable effort had been made to determine the appropriate method of data retrieval given the constraints of time and costs. Since very little time-series data on solid wastes were available on a comparative basis, it was deemed appropriate to incorporate only spatial data, on a cross-section basis, into the model.

Data Development-Current Status

Solid Waste Production.--The development of spatial waste production profiles for the San Francisco Bay region and its constituent D.S.A.s is of prime consideration. For the Bay Area, the waste production data are being derived from on-site interviews with disposal site operators and the scavenger companies which collect the refuse for the region. The methodology for solid waste data retrieval was initially established during the first year of study when a preliminary survey of Santa Clara County was undertaken. During this pilot study, mailed surveys and personal interviews were used to develop the data required for the analysis of the area. This approach was adequate for the analysis required and plans were drawn to incorporate this method into the Bay Area study. Upon completion of the

pilot study and before embarking on the Bay Area study, an agreement was reached with the California Department of Public Health, according to which they would supply the required data on solid waste generation.

The actual data collection procedures used by the California Public Health Department involved a specific timetable for interviewing and surveying particular counties. Accordingly, the nine Bay Area counties were surveyed by the Public Health Department at different times. The Santa Clara County survey was completed in February 1967. In March 1967, surveys of San Francisco and Sonoma Counties were completed. The Napa County survey was completed in April, surveys of Contra Costa and Marin in May, and of Solano and San Mateo Counties in June of 1967. The survey of Alameda was finished by the end of September 1967. The variation in reference periods, together with certain inherent data difficulties, gave rise to some discrepancies. Special efforts had to be made to reconcile these discrepancies as far as possible to reduce the inconsistencies of the data before they could be analyzed.

Each of the operators of the 130 (or more) disposal sites within the region has been personally interviewed by the California Public Health group. Usually, estimates were based on the characteristics of the collection vehicles, their routes, and the amounts in the fill that could be ascertained. The data were expressed as tons per day, and were based upon the month-to-month average daily amounts taken in during the year preceding the survey. Since the dates of each county's interviews varied, some non-comparability also exists between the per diem averages.

When the actual amounts of wastes could not be obtained, close approximations were attempted with the use of a variety of methods. The methods included making a percentage estimate of the amounts of each category contained in each truckload, using as a basis information on known routes and known load categories and quantities obtained in other surveys; estimation of the percentage of waste in the site in cubic-yards or acre-feet per year and, taking into consideration the average compaction ratios for the site, converted to tons per day. The final accuracy of the solid waste data depends on how far the discrepancies have been reconciled.

The solid waste data collected by the California Public Health Department interviewers are virtually complete and are being checked for internal consistency.

Population.--The objective in gathering data on population was to obtain the information with which accurate and reliable population estimates could be made for comparable and recent time periods for the 31 disposal service areas defined in this study. Since the disposal service areas are composed of census tracts (or parts thereof), population estimates need to be developed for all the census tracts or parts of census tracts within a disposal service area.

The period January 1, 1966 to January 1, 1967 was decided upon as being a reasonably comparable one. The reference period for population will be adjusted to that of solid waste data when the latter are established. There may be slight variations in reference time periods between disposal service areas, but for each area all the pertinent data will be related to the same period of time as far as possible.

Whenever a disposal service area boundary line divided a census tract, an intelligent apportionment of the population was made in consultation with public officials and private sources in the locality.

The problems of reliability and accuracy can never be completely and satisfactorily resolved. Santa Clara County, in which a special census was taken in April of 1966, is the only county in which an official count was made since the 1960 census. Methods of estimation vary in the other counties. Sources of population data, methods (where known) of estimating population numbers, the dates of the estimations, limitations of the data, and adjustments made by the research team are described in Appendix B.

Employment.--Data on employment are available at the highest level of detail as compared to other variables in this study. It is planned to make maximum use of employment data not only in the model but also later when the results of auxiliary studies by the California Department of Public Health regarding industrial and manufacturing wastes factors become available.

The primary data on employment were tabulated by the California Department of Employment. The data are available by census tracts and also by detailed categories of enterprises familiarly known as the Standard Industrial Classification code (at the four-digit level). These data have been used by various public organizations, and particularly by the Association of Bay Area Governments and in the Bay Area transportation studies. The problems involved in using the data have to do with the time period, coverage and uniformity.

After obtaining the basic data, the next step was to group employment by census tracts (or portions) to correspond to the D.S.A.s already established for the purpose. The mechanical problems of actually "handling" the data also add to the problem in a minor way, but these are being eliminated by preliminary runs and making group totals before the final run is made. Finally, aggregation will conform to meaningful groups corresponding to the waste categories defined earlier.

The employment data will be instrumental in locating industrial waste loads originating in different D.S.A.s, whenever primary data on solid wastes can not be obtained with a reasonable degree of accuracy.

Land Use.--Information on land use for the nine-county San Francisco Bay Area was proposed to be obtained from the Bay Area Transportation Studies on the Bay Area Simulation Studies. Maximum use of these data will be made in future phases of our study. In the immediate future, it is planned to make use of the land-use and other economic data and forecasts developed by the University of California Center for Real Estate and Urban Economics in the Bay Area simulation study, since for the time being, the timetable of B.A.T.S.C. for the completion of the compilation of their data does not coincide with that for our study. The University of California data are based on aggregated land use categories. These will be utilized for running preliminary regression equations.

Land use data can be used in two important ways. Firstly, they can be used to constitute one of the explanatory variables--possibly for explaining agricultural wastes by types. Secondly, the land use information can also be used in conjunction with land use planning for the region, to suggest ways and means to consider future location of land for waste disposal plants as a part of the overall planning process. This aspect of the work and various other facets mentioned in the "Background" and others yet to be formulated in greater depth, will form the subjects of investigation for the remainder of the current year and for our future years of research on solid waste management.

Income: Data on household income are available for 1965-66 only by counties and in some cases by cities. Efforts are under way to utilize the 1960 census figures on income to apportion the total income by Census tracts for re-aggregation corresponding to D.S.A.'s.

The data described above are being tabulated on the computer Center facilities of the University of California at Berkeley. The results of the regression studies and other facets of the research work under progress will be reported in future meetings.

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