THE ANALYSIS AND PREDICTION OF THE QUANTITY AND COMPOSITION OF HOUSEHOLD REFUSE

NICHOLAS MARK RUFFORD

A Thesis Submitted in Partial Fulfilment
of the Degree of

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Department of Civil Engineering

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SUMMARY

This thesis describes the development of a simple and accurate method for estimating the quantity and composition of household waste arisings. The method is based on the fundamental tenet that waste arisings can be predicted from information on the demographic and socio-economic characteristics of households, thus reducing the need for the direct measurement of waste arisings to that necessary for the calibration of a prediction model.

The aim of the research is twofold: firstly to investigate the generation of waste arisings at the household level, and secondly to devise a method for supplying information on waste arisings to meet the needs of waste collection and disposal authorities, policy makers at both national and European level and the manufacturers of plant and equipment for waste sorting and treatment.

The research was carried out in three phases: theoretical, empirical and analytical. In the theoretical phase specific testable hypotheses were formulated concerning the process of waste generation at the household level. The empirical phase of the research involved an initial questionnaire survey of 1277 households to obtain data on their socio-economic characteristics, and the subsequent sorting of waste arisings from each of the households surveyed. The analytical phase was divided between (a) the testing of the research hypotheses by matching each household's waste against its demographic/socioeconomic characteristics (b) the development of statistical models capable of predicting the waste arisings from an individual household and (c) the development of a practical method for obtaining area-based estimates of waste arisings using readily available data from the national census. The latter method was found to represent a substantial improvement over conventional methods of waste estimation in terms of both accuracy and spatial flexibility.

The research therefore represents a substantial contribution both to scientific knowledge of the process of household waste generation, and to the practical management of waste arisings.

WASTE DISPOSAL, MUNICIPAL REFUSE, WASTE COMPOSITION, ANALYTICAL METHODS, MATHEMATICAL MODELLING

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CHAPTER ONE

RESEARCH BACKGROUND, AIMS AND SUMMARY

1.1 General Introduction to the Research

1.1.1 This thesis describes the development of a method for estimating the quantity and composition of household waste arisings. The method is based on a computer model which predicts a household's average weekly production of dry domestic waste from data describing the socio-economic, demographic and behavioural characteristics of the household. The model enables the total waste arisings of an area such as a refuse collection round or a disposal catchment to be estimated simply and accurately using available census data held on computer file.

1.1.2 In this first chapter of the thesis the research aims and specific objectives are set out and the justification for the research is established in terms of the failure of existing methods of waste estimation to meet the current needs of the 'wastes industry'. The chapter then summarises the research methodology, the results obtained and the general contribution which the research makes to knowledge. A synopsis of the remaining chapters is also provided.

Research Aims

1.1.3 The aims of the research are twofold: firstly to improve current understanding of the nature and variability of household waste by investigating at the household level the factors which affect the process of household waste generation; and secondly to develop a method that is of practical value in waste management contexts for deriving information on the total quantities and composition of household waste generated within predefined areas.

1.2 The Emerging Need for Improved Information on Household Waste Arisings

1.2.1 The need for fundamental research into household waste arisings derives from the need for a better scientfic understanding of the waste generation process and the need for an improved method for obtaining information on waste arisings. The nature and evolution of these needs are the subjects of the following sections.

1.2.2 The management of household waste was once characterised by low technology and dominated by the almost exclusive use of untreated tipping as the method of disposal. Recent trends, particularly in the last ten years, have transformed and upgraded the status and technology of the wastes industry. The changes within the industry are the result of pressures in four areas:

(1) The increase in the costs of disposal of domestic and commercial wastes. Gross expenditure on waste disposal by local authorities increased from £71M as in 1973 to £108M as in 1979 at constant 1977 prices (OECD 1982).

(2) The shortage of suitable sites for landfill purposes. This is reflected in the decline in the proportion of untreated waste sent to landfill, from 77% in 1975 to 71% in 1978, and to 68% in 1981 (DoE 1981, CIPFA 1982).

(3) The growth in public concern over the environmental impacts of waste disposal and about the depletion of finite resources resulting from the use of destructive disposal practices.

(4) The recent availability of new processes and technologies, particularly for the mechanical separation of household waste and the subsequent recovery of secondary materials.

1.2.3 As a result of these pressures for greater efficiency and economy, together with pressures for greater regard for environmental issues, substantial advances have taken place in waste management. The most significant advances include the development of waste recovery and refuse derived fuel plants, the increased use of intermediate refuse transfer and pre-treatment facilities, and the adoption of more rigorous disposal standards to ensure that refuse is disposed of in an environmentally acceptable manner. The use of more sophisticated technology and practice has been accompanied by the need for more detailed and accurate information on waste itself. The more stringent specifications and finer tolerances of the new techniques and technologies have meant greater sensitivity to the precise quantity and composition of waste that arises in an area; they have also meant a greater sensitivity to the variation in the characteristics of waste between different areas, and to changes in waste arisings over time, including both the seasonal fluctuations and the longer-term trends.

1.2.4 In addition to the demands for improved waste information created by the general developments within the wastes industry, two further factors have led to a greater demand for waste information, specifically by waste disposal authorities. These factors are firstly the increased competition for void space in suitable disposal sites which has obliged disposal authorities to justify their claims for available space with accurate information on current and future waste arisings; and secondly the implementation of Part 1 Sc. 2 of the Control of Pollution Act 1974 which requires waste disposal authorities to prepare disposal plans containing estimates of current and future levels of all types of waste generated in their areas.

1.2.5 A number of aspects of waste management can therefore be identified as being those most likely to benefit from improved waste information:

(1) The appraisal of alternative disposal/recycling options in order to match the most appropriate option

to existing and likely future waste quantity and type.

(2) The planning of the location, capacity and design of disposal facilities in general.

(3) The design of waste collection rounds in order to supply waste recovery plants with the most suitable type of waste.

(4) The design of waste handling, treatment and storage facilities.

(5) The estimation of tip lifespan and estimation of required future disposal capacity.

(6) The monitoring of sources of potentially toxic or otherwise harmful or intractable materials in household waste.

(7) The monitoring of levels of packaging materials in household waste to determine the burden placed on waste services by particular types of product.

1.2.6 The specific demands for information in relation to each of these areas of waste management are discussed in detail in Chapter 3. From the consideration of the practical needs of the wastes industry with regard to waste information a set of specifications emerge which form the basis for the design of a new method for waste estimation. A summary of the specifications is given retrospectively below in order to provide a framework for the evaluation of existing estimation methods.

(1) The method should be simple and cheap to implement and use readily available data.

(2) The method should be capable of estimating the quantity and composition of both present and future household waste arisings.

(3) The method should be applicable to a range of spatial scales to correspond to the diverse aspects of wastes management (e.g. collection, disposal, regional planning).

(4) The method should be sufficiently sensitive to variations in waste characteristics to measure the effects of alternative decisions in wastes management.

(5) The method should be valid, reliable and robust.

1.2.7 The above discussion has centred on the purely practical needs for improved information on household waste arisings. However, there is a second strand to the research which is concerned with developing a more scientific understanding of the complex processes which underlie household waste generation and which account for and explain the variation in waste quantity and composition between different households. Household waste is a function of a large number of different activities which take place both within the community and inside the individual household. Figure 2.1 (page 32) summarises the diverse range of factors which influence waste generation. Chapter 2 contains a detailed discussion of these factors and the mechanisms by which they affect waste generation. In summary, household waste may be regarded largely as the end product of the purchasing activity of households. Approximately eighty percent of all household waste derives initially from consumer goods (Merseyside County Council 1981, Rufford 1982). Two separate sets of factors influence the types and amounts of materials passing through the household: supply factors such as state of technological development and raw materials prices, and demand factors including household income, age distribution and tastes and preferences. These factors interact with other household characteristics (such as access to waste disposal outlets other than the dustbin) to determine the ultimate nature of waste arisings. No past study on which information is available has attempted to systematically quantify the variation in waste between individual households and attribute it to the effects of the various relevant factors. Concluding a review of contemporary research into household waste in the USA Rao (1971) observes:

> "we do not completely understand solid waste generation, even in the presumably simple household system."

The neglect of this research area in the past accounts for the poor theoretical underpinning of existing methods of waste estimation (see section 1.3). The investigation of the way in which specific measurable factors influence the amount and type of household waste generated is therefore of intrinsic scientific value in its own right, as well as being an essential precondition to the development of a useful and effective method of waste estimation.

1.2.8 This section has outlined the needs for more detailed and accurate waste information both as a practical tool, and to enhance theoretical knowledge. The extent to which these needs justify new research depends on the extent to which existing methods of waste estimation are able or unable to supply that information.

1.3 Existing Methods for the Estimation of Household Waste Arisings

1.3.1 This section describes and critically examines existing methods for waste estimation. Each method is evaluated against a set of criteria based on the demands and constraints implied by the practical needs of the waste industry for information of a suitable form and type and together with theoretical issues of validity, reliability and robustness. These practical and theoretical issues are discussed in greater detail in Chapters 2 and 3 respectively. A table containing a summary evaluation of existing methods as included at the end of the section (Table 1. 1).

1.3.2 The various approaches to waste estimation can be classified according to the scheme in Figure 1.1. The three methods shown are discussed below.

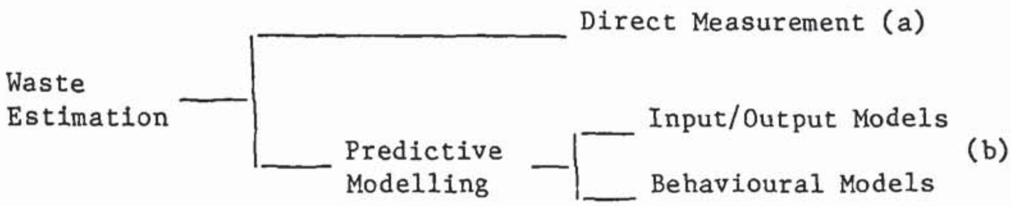

Figure 1.1 Taxonomy of Waste Estimation Methods

(a) Direct Measurement methods involve the measurement of waste arisings in isolation from the factors which account for their generation. In principle it would be possible to determine exactly the amount of household waste in an area by weighing all waste as it entered disposal sites. In the UK an estimated 41% of all domestic and commercial waste is weighed in this way (CIPFA 1982). However this approach gives no indication of refuse composition and it is also time consuming, requiring the regular measurement of vehicle laden weights. In addition, direct measurement provides no basis for the prediction of waste arisings in other areas or time periods since it does not take into account any of the social, economic or technical factors which affect waste arisings. There is also doubt concerning the accuracy of weighbridge data for the reason that only a fraction of total waste arisings are actually weighed. The weight of the remaining fraction is inferred by scaling up the average weight of a full refuse load with a count of the number of vehicles entering the disposal site. Because vehicles are often less than fully loaded this practice has led to suggestions that weighbridge data tends to overestimate the true levels of waste arisings (DoE 1975a).

(b) The alternative approach to direct measurement is predictive modelling. This method involves estimating waste quantities from the measurement of other factors chosen as indicators of waste arisings. The types of predictive approach are the input/output model and the behavioural model.

1.3.3 Input/Output Models are based on the concept that waste can be predicted from a knowledge of the quantities and types of materials that enter the economic production/consumption chain at some distance removed from the point of disposal. The point of entry may be the input of raw materials to manufacturing industry (Bailly and Tayart de Borms 1977, Doggett et al 1980) or else the consumption of finished goods (Boyd et al 1971). The input/output approach is subject to a number of criticisms.

(1) The problem of time lags between production, consumption, and disposal introduces considerable uncertainty into waste estimation.

(2) Unless goods are produced, consumed and disposed of inside a closed system there is a problem of 'leaks' through materials entering or leaving an area. The method is therefore unsuitable for areas without distinct boundaries such as collection rounds.

(3) The method is generally demanding in terms of data input in the form of material inventories and product inventories, and also in terms of data analysis to take account of process losses, imports, exports, recycling etc.

1.3.4 Subsumed under the general heading of behavioural models are number of different model types, namely the 'per capita' method, category models, econometric models and multivariate taxonomic techniques (Figure 1.2).

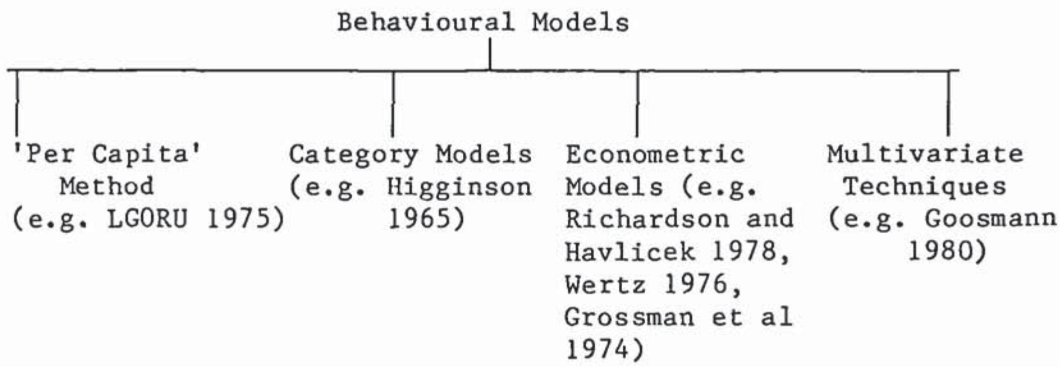

Figure 1.2 Taxonomy of Behavioural Waste Models

The simplest example of a behavioural type model is the per capita method. In this model an average per capita waste generation figure is obtained and combined with a population figure to derive an estimate of waste for an area. A population forecast can be used to derive an estimate of future waste arisings. The method assumes that all individual members of the population generate equal types and amounts of waste. It cannot therefore discriminate between areas with equal populations but contrasting socio-economic characteristics.

1.3.5 Category models are more sophisticated in that they take account of the fact that different categories of waste producer have different waste-generating characteristics. The current standard UK technique for estimating household waste arisings, attributable to Higginson (1965), is an example of a simple category model. This method determines the average quantities of waste from four different types of household are determined by sorting and analysis; these averages are then multiplied by the numbers of each type of household in the survey area to obtain a total estimate of waste arisings. The main criticisms of the method are:

(1) Property type can at best be only a surrogate for the underlying factors which cause different households to generate different types and amounts of waste.

(2) The recommended procedure for determining the average waste levels for each category of property (a bulked sample of one hundred households drawn from the same collection round) does not make provision for the measurement of error; neither is it based on a valid sampling procedure.

(3) Information on property types is generally only available at the level of the administrative distinct and the method is therefore unsuitable for estimating the waste arisings from smaller areas such as collection rounds.

1.3.6 A more sophisticated version of this type of model has been developed in Denmark by GENDAN (1981)*. GENDAN sorted a total of 13 tonnes of household waste collected from 1182 households over a one year period. Each household's production of waste was matched against information on its socio-economic characteristics obtained by household questionnaire and from the electoral register. GENDAN found that household size was 'the single most important parameter determining the quality and composition of waste.' Using property type as a basis for waste estimation (in this context as a surrogate for household size), GENDAN went on to develop a category model based on three different classes of property: 'parcel houses' (i.e. prefabricated houses the equivalent of modern family homes in the UK), flats and owner occupied residential homes. By combining a 'reference waste' (i.e. average waste figure) for each different type of property with information on the spatial distribution of property types in Denmark, GENDAN report that they are able to make estimates of waste arisings for the whole country. The basic approach adopted by GENDAN is similar in principle to the approach taken in this research. However the use of property type as a surrogate for other, more fundamental socio-economic variables is restrictive.

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* Based on an interim report published in Danish.

1.3.7 Multivariate taxonomic techniques may be used to classify urban sub-areas into groups or types which are similar in terms of a set of variables hypothesised to be related to household waste generation. The groupings then serve as a basis for the sampling of waste. This approach was used by the Technical Institute of the University of Berlin to estimate waste arisings in the City (Goosmann 1980). Between thirty and forty percent of the variance in total waste between sub-area types is reported to be explained as a result of classifying ninety six urban areas in Berlin into three groups on the basis of eight socio-economic variables. The main criticisms of the approach are:

(1) The system of classifying areas is based on aggregate areal characteristics as opposed to the characteristics of the households within the areas. The classification does not, therefore, reflect the fundamental unit of waste generation.

(2) The sub-area types generated by the procedure cannot be used directly as a basis for forecasting since no information is available about how the size or configuration of area types is likely to change over time.

1.3.8 The econometric approach involves the formulation of a mathematical model and the use of statistical techniques to obtain estimates of the model parameters. The general model form is:

$$Y_a = B_1 X_1 + B_2 X_2 + B_3 X_3$$

where Y_a = quantity of waste type a

and X_1, X_2, X_3 are variables describing the unit of waste generation

and B_1, B_2, B_3 are coefficients

The advantage of the econometric model is that it can be used to predict waste levels in unsurveyed areas and time periods, provided that estimates of the explanatory variables are available and provided that the model is technically valid. Past attempts at applying econometric models to waste estimation (Richardson and Havlicek 1978, Wertz 1976, Grossman et al 1974) have used area data on city blocks or census districts to estimate the model parameters. Implicit in the use of aggregate data is the assumption of independence among the explanatory variables. If there is interaction among the variables then the use of aggregate data in this way is inappropriate.

1.3.9 Table 1.1 is a summary of the relative strengths and weaknesses of available methods for waste estimation. Existing practice used in the UK, together with other published approaches, are evaluated against the criteria outlined previously in section 1.2.6 and 1.3.1. The notation used in the Table consists of a (✓) to show that a particular method satisfies a criteria or alternatively a brief explanatory statement where a method either wholly or partially fails to satisfy a criterion. For example, the table indicates that the 'weighbridge method' is relatively cheap and simple and yields data on the most basic unit area of interest in the context of waste management, namely the collection round. However, the table also shows that the method does not provide information on waste composition and cannot be used as a basis for prediction.

1.3.10 From the discussion above it can be seen that behavioural models are potentially the best methods for waste estimation. They have the advantage of being geographically flexible, they can be used for prediction, they are simple to implement and they can make use of readily available data. Existing behavioural approaches however tend to be subject to criticism because of weaknesses in model design. The main problems are:

(1) The explanatory factors used are poor indicators of waste.

(2) Inter-relationships in the models are not adequately specified, in most cases because the models are based on area data rather than household data.

Consequently, there is a need for a more rigorous behavioural approach which is both powerful and valid (i.e. based on theoretically sound and preferably causal relationships). The work reported in this thesis seeks to respond to these needs within the framework of the specifications already set out. The next section gives a more detailed account of the specific research objectives.

Table 1.1 Summary Evaluation of Existing Methods of Waste Estimation

Method	Evaluation criteria	Appropriate method of waste categorisation and measurement	Applicable over appropriate units of area	Simple and cheap to apply and based on readily available data	Provides basis for forecasting waste arisings	Theoretically valid, reliable and robust
Current UK Practice	Weighbridge method	Total waste quantity only considered	✓	✓	Provides no basis for prediction	Not reliable
	Per capita method	Total waste quantity only considered	✓	✓	✓	Assumes that individuals generate equal types and amounts of waste
	Higginson method	Waste composition considered in terms of 'standard eight' waste categories	Smallest area of resolution corresponds to planning district so unsuitable for collection/disposable areas	✓	Provides no basis for prediction	No provision for estimating error and not based on valid sampling procedure
Published Alternative Methods	Input/Output type models	✓	Applicable only at high level of resolution e.g. national scale	Requires extensive data input and analysis	✓	Uncertainty introduced by time lags
	Econometric type models	✓	✓	✓	✓	Existing versions tend to be invalidated by use of aggregate data
	Multivariate statistical techniques	✓	✓	Requires extensive data analysis to classify urban sub-areas	Provides no basis for prediction	✓

1.4 Research Objectives

1.4.1 The explicit objectives of the research are:

(1) To quantify variations in waste levels between households and to distinguish between random and non-random components of variation.

(2) To compare the quantity and composition of waste produced by different types of household as defined by socio-economic and other characteristics.

(3) To explain and predict waste quantity and composition through a household based model.

(4) To develop an area-based model to obtain household waste information in a form which is appropriate to the practical needs of waste management.

1.4.2 The objectives are based around three considerations which derive from the fundamental aims of the research while at the same time acknowledging the constraints imposed by the limited time and resources available for the research. The considerations are:

(1) Any attempt to establish a scientific understanding of waste arisings needs to begin by investigating the waste generation process at the level of the individual household, with the objective of quantifying and attributing waste variation to the relevant sources.

(2) It is necessary to recognise that household waste is collected and disposed of in bulk. In order to be of value in waste management contexts a waste model must be capable of estimating waste arisings from areas corresponding to zones of practical interest such as collection rounds and disposal catchments.

(3) Constraints of time and resources impose limits on what the research is able to achieve. The experimental phase of the work is therefore confined to the investigations of one dimension of waste variation, namely cross-sectional differences in waste arisings among households within one region and a single time period.

1.5 Research Methodology

1.5.1 The research objectives set out in the previous section were pursued through a research method comprising several discrete phases. These included developing a theoretical model of household waste generation, conducting an extensive field survey of dustbin waste in Birmingham and carrying out a programme of data analysis involving hypothesis testing and model specification and calibration.

1.5.2 The initial theoretical phase of the work consisted of a desk top study of the process of household waste generation, drawing on previous studies of household waste arisings and studies of consumer behaviour. From this theoretical exploration a series of hypothesis were developed relating waste arisings to measurable household characteristics. Examples of the types of factors considered are:

- Property type and tenure
- Occupation of the head of household
- Household size
- Age structure of the household
- Type of domestic heating
- Ownership of cars, freezers and domestic pets
- Mode of newspaper purchase
- Frequency of shopping trips for food.

1.5.3 The experimental phase of the work involved a case study of household waste arisings in the Birmingham area during the autumn and winter of 1982. The study is believed to be the most extensive survey of its kind yet carried out in the UK. Fifteen hundred households were interviewed during the first stage of the survey. The intention was:

(a) To gain the housholders' consent for the survey.

(b) To obtain information on relevant household characteristics.

(c) To structure the sample of households.

The interviews included questions on household characteristics hypothesised to be the main factors underlying the generation of household waste. Households were selected in such a way as to represent a complete cross section of these factors in accordance with the principles of factorial design (described in detail in Chapter 4). One week's refuse was collected from each of the households included in the survey (problems of access to homes reduced the number of dustbins finally analysed from 1500 to 1277). The dustbin contents were then handsorted into fifteen waste categories and weighed. The method of categorisation, shown in Table 1.2, represented a far more detailed breakdown than the 'standard eight' categories used in past UK waste surveys (Higginson 1965, Birch 1976, Ling 1976, Merseyside County Council 1981). The detailed compositional analysis was an essential pre-requisite to the development of a deeper theoretical under-standing of the process of household waste generation; it was also directly relevant to the needs of the users of waste information. The data on waste quantity and composition for each household was matched against the corresponding questionnaire data on the household characteristics to obtain a data set consisting of 1277 cases. Also included in the experimental phase were:

(1) A repeat analysis of waste from selected households over a period of three weeks to examine the 'random' fluctuations in a household's weekly refuse.

(2) An exercise to determine the extent of error inherent in the handsorting and measurement of waste.

Table 1.2 Categorisation of Waste Devised Specifically for the Research and the DoE Equivalent

WASTE CATEOGRY	DEPARTMENT OF THE ENVIRONMENT EQUIVALENT CATEGORY
Kitchen waste Garden waste	) Vegetable and) Putrescible
Scrap paper and paper packaging Newsprint Cardboard	) Paper and board
Ferrous Metals Non-ferrous metals	) Metals
Textiles	Textiles
Glass	Glass
Plastic film Dense plastic	) Plastics
Miscellaneous Combustible Miscellaneous Non-combustible Pernicious items	) Miscellaneous
Fines < 2cm	Screenings

1.5.4 In the analytical phase of the work the associations between household characteristics and waste arisings were statistically examined using one-way analysis of variance. The procedure served both as a means of hypothesis testing and also as a method for 'sieving out' the most important explanatory factors for inclusion in the next stage of the analysis, namely the development of a statistical model. Two alternative approaches to modelling household waste generation were investigated. The first approach was based on the 'category model' principle and involved obtaining waste generation coefficients for a range of household types. Categories of household were defined on the basis of factors which had emerged in the preceeding analysis of variance as those most strongly related to waste arisings. The second modelling approach used a multivariate statistical technique called principal components analysis to conflate the explanatory factors into a smaller set of mutually orthogonal synthetic variables. This process recognised the fact that many of the factors investigated were indicators of the same underlying constructs (e.g. property type and property tenure). Each waste type was regressed separately against the set of 'principal components' to obtain a series of regression models. The final stage of the analysis was the development of a method for deriving area-based estimates of waste arisings. Twenty four categories of household were defined taking account of the sources of household data available within the West Midlands. For each category of household a waste generation coefficient was derived.

Estimates of waste arising were then obtained for two test zones of contrasting size in order to demonstrate the versatility of the technique. The results of the analytical phase of the research are summarised briefly in the next section.

1.6 Summary of Results

1.6.1 The detailed results of the research are presented within the main discussion of the analytical methods in Chapters 5, 6 and 7. The following account is a summary of the main findings of the research:

(1) The average quantity and composition of waste arisings among the households surveyed were found to be comparable with the results of other contemporary surveys carried out in the UK (e.g. Merseyside County Council 1981, Higginson 1981). Cross-comparison was made possible by grouping the fifteen waste categories into the 'standard eight' classes of refuse (q.v.). Observed differences between the research findings and the results of existing surveys were attributed partly to refinements in the waste measurement technique used in the present research to overcome errors inherent in conventional handsorting techniques.

(2) Substantial variation in both waste quantity and composition was found between households. For example, the range in total weight of waste arisings was 54 kg/hh/wk while

the proportion of kitchen waste varied from 0 to 93 percent by weight of total waste. For every type of waste with the singular exception of kitchen waste the standard deviation of the weight of waste exceeded the mean weight.

(3) Repeat sampling of individual households indicated that only 16 percent of the variation between households in total waste arisings was attributable to random week-to-week variation. By implication, therefore, 84 percent of total waste variation was found to be attributable to substantive differences between households.

(4) The application of one-way analysis of variance showed that, in statistical terms, the majority of factors included in the questionnaire were significantly and substantially associated with waste arisings. Factors that were highly correlated with all, or nearly all, types of waste included: household size, occupation of the head of household and stage in the 'Family Life Cycle' (see section 2.11.5). Other factors tended to exhibit a specific relationship with a particular waste type (e.g. 'type of domestic heating' with 'fines').

(5) By combining household factors into the form of a statistical model it was possible to explain 26 percent of the variance in total waste levels between

households, equal to 31 percent of the non-random component of variance. This represents around five times the variance explained by the traditional 'Higginson method' (q.v.) of waste estimation which uses property type alone as a basis for prediction. The proportion of explained variance was slightly less for the individual waste components.

(6) Estimates of waste quantity and composition were successfully obtained for all census enumeration districts within a selected Birmingham electoral ward, as well as for the entire Birmingham Metropolitan Borough. The patterns of arisings indicated that different household type, with different waste generating characteristics tend to group together into discrete neighbourhoods, each with a distinctive 'waste profile'.

1.7 Conclusions

The theoretical study of household waste and the survey and analysis work carried out represent a contribution both to the scientific understanding of the process of waste generation and to the practical needs of waste management. The significant and substantial nature of differences in waste quantity and composition between households have shown that waste generation is a systematic process which can be usefully simulated using a statistical model. The research has also demonstrated the potential strength and usefulness of a statistical model for discriminating between the waste arisings of different areas. The specific innovations attributable to the research are:

(1) As part of the experimental phase of the work a new system of categorising waste was developed to take account simultaneously of the origins of waste and the information needs of waste managers.

(2) A theoretical model was developed relating waste arisings to household characteristics.

(3) An extensive survey of household waste arisings was carried out, yielding data on the average amounts and types of waste generated by households, on the relative degrees of random and non-random variation in waste arisings and on the differences in waste arisings between households of different type.

(4) Alternative forms of statistical model were developed to explain and predict waste arisings. The performance of the models represents an advance over conventional methods of waste estimation.

(5) A simple and geographically flexible technique was designed for obtaining area based estimates of waste quantity and composition.

1.8 Synopsis of Remaining Chapters

The remainder of the thesis is set out in successive chapters as summarised in Figure 1.3. Chapter 2 contains a discussion of the process of household waste generation, drawing largely on available literature and existing research. Chapter 3 examines in detail the specific needs of the wastes industry with respect to the content and form of information on wastes. Chapter 4 describes the design of a research method to meet the theoretical and practical demands set out in the previous two chapters, taking account of issues of measurement, sampling and statistical analysis. Chapter 5 sets out the results of the experimental phase of the work and Chapter 6 describes the methodology and results of the hypothesis testing and model building phases. Chapter 7 is an account of the development of a method for the area-based estimation of waste arisings and includes a demonstration of the method in operation. Chapter 8 contains recommendations for extending the boundaries of the model both to take account of the regional differences in waste arisings and the changes in waste arisings which occur over time. A final summary of the research together with an appraisal of the method and recommendations for further work is provided in Chapter 9.

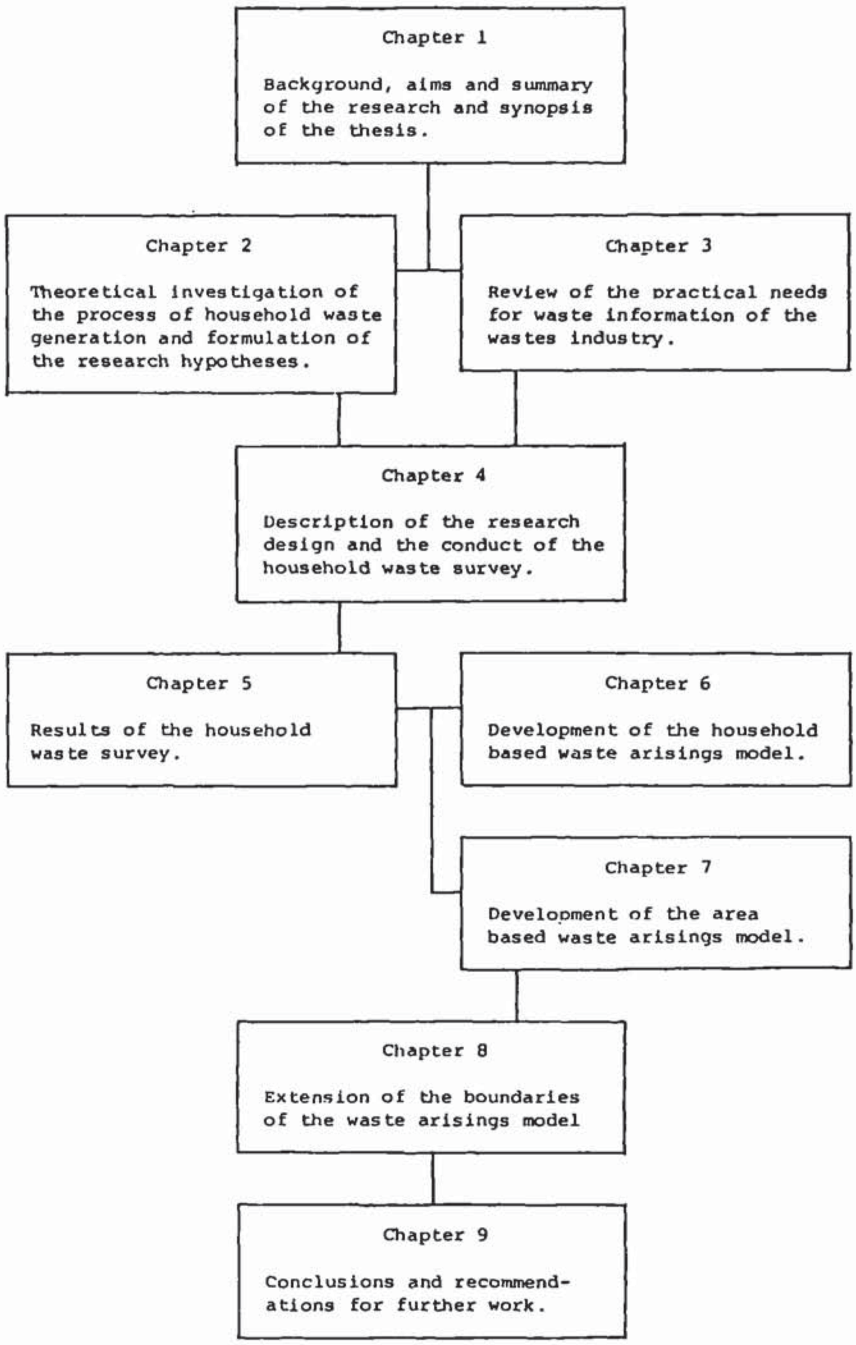

Fig. 1.3 Diagramatic representation of the thesis layout

CHAPTER TWO

THEORETICAL BASIS OF THE RESEARCH AND HYPOTHESIS FORMULATION

2.1 Introduction and Aims

2.1.1 This chapter establishes a scientific basis for understanding and explaining the generation of waste arisings at the household level. This investigations of the process of waste generation serves two purposes: it provides a theoretical underpinning for the development of an empirical waste arisings model, and it contributes directly to the theoretical knowledge of the subject. The evidence used in the investigation is derived from existing theoretical and empirical studies concerned either directly with household waste arisings or indirectly with some process underlying the generation of household waste. By drawing together these various sources of information a series of explicit testable hypotheses are derived. These attempt to explain the variation in the quantity and composition of waste arisings that occurs both between households and over time. The hypotheses consist of a series of statements relating specific categories of waste to measureable household factors. As part of the theoretical investigation a new system of waste categorisation is developed which groups household waste according to its origins. This represents a refinement in context of the old system of categorisation based on the physical characteristics of waste.

2.1.2 The theoretical investigation in this chapter begins with a hypothetical model of household waste generation. The model provides a generalised understanding of the waste generation process and an organisational framework for the subsequent discussion of the factors which underlie waste generation. The bulk of the Chapter (sections 2.3 to 2.7) is concerned with the role of the household as a consumer of and disposer of, commodities. As noted in Chapter 1, a substantial proportion of household waste is derived from consumer items and a household's consumption activity will therefore have a direct bearing on its waste arisings. The other main groups of factors discussed in this Chapter are those related to the generation of non-consumer waste by the household (section 2.8) and the household's use of 'alternative' disposal pathways (such as sink disposal units) which effectively divert waste away from the dustbin (section 2.9). All of these various groups of factors are brought together in section 2.10 which discusses how the research hypotheses were formulated to relate the factors describing the characteristics of the household to the characteristics of the waste likely to be generated.

2.2 A Theoretical Approach to the Waste Generation Process

2.2.1 Waste is the result of the interaction of a large number of activities which take place within the economy and the community and inside the individual household. The various types of activities and processes are summarised in Figure 2.1 in the form of a schematic diagram. The diagram

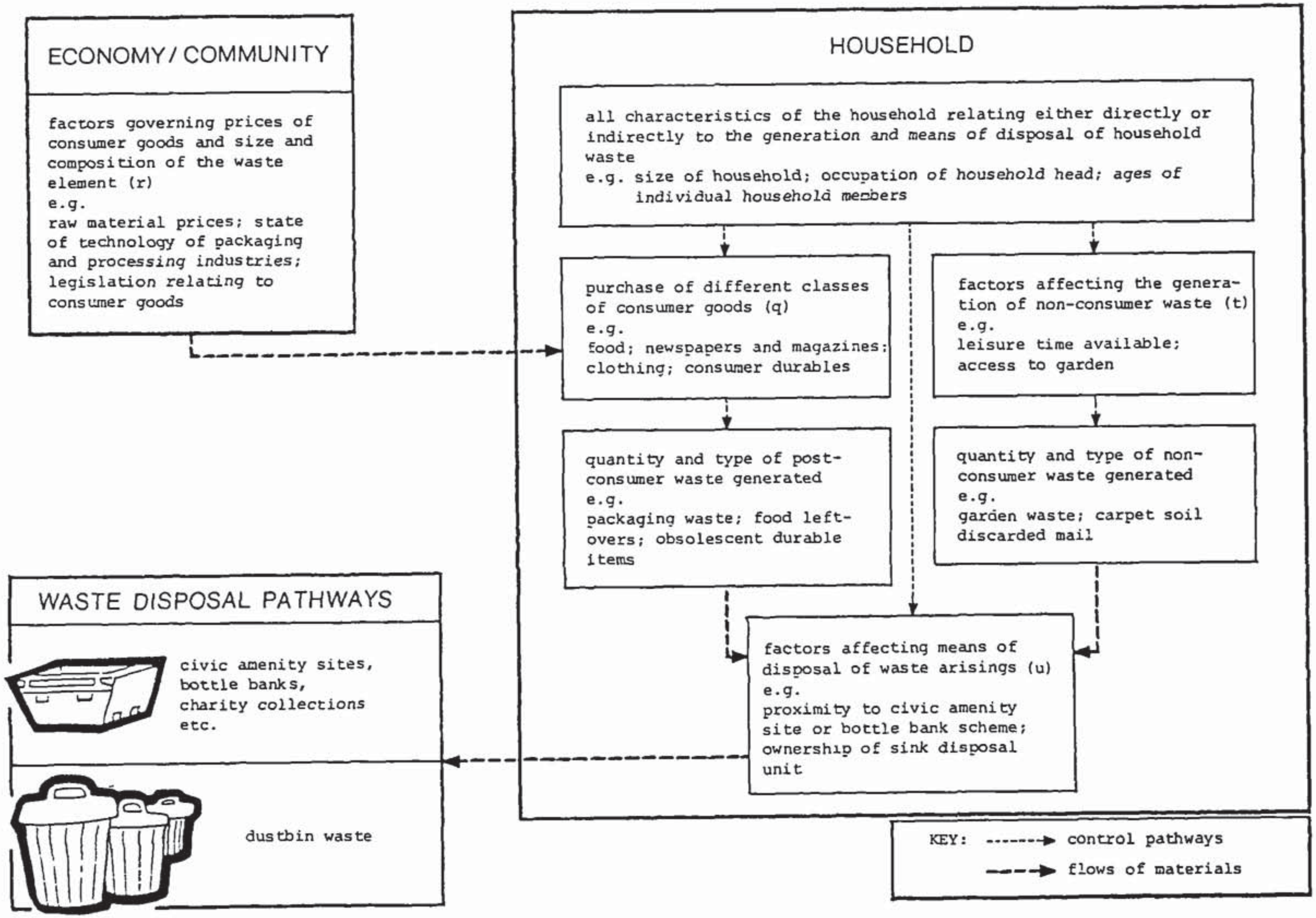

Fig. 2.1 Schematic diagram showing the flow of waste through the economy and the household

indicates that household waste consists of waste which arises by two fundamentally different processes. Firstly, waste occurs as a result of the household's participation in the consumption of externally produced goods and services. This is termed post consumer waste (PCW) in Figure 2.1 after Boyd et al (1971). Secondly, waste is produced as the result of activities which take place inside the household itself (e.g. maintenance, cleaning, gardening etc). This is termed non-consumer waste (NCW). The factors affecting the quantity and type of waste produced by the household can therefore be divided initially into:

(1) those factors which account for the production of post-consumer waste.

(2) those factors which account for the production of non-consumer waste.

2.2.2 As well as being a 'waste producer' the household is also a disposer of waste. There are a variety of alternative pathways, aside from the dustbin, by which a household might choose to dispose of its waste. These include waste taken to civic amenity sites and food leftovers fed to pets. A third group of factors can therefore be identified which have a bearing on the waste generation process, namely those which intervene between the initial production of waste and its ultimate disposal via the dustbin.

2.2.3 One of the fundamental tenets of the theoretical approach taken in this research is that the process of household waste generation can only be adequately understood, and hence simulated, at the household level (as distinct from the level of the individual population member or the collection round or the census district). This approach is vindicated by examining the level of aggregation at which the three groups of factors identified above affect waste arisings:

(1) In terms of consumption activity the household is, by definition, a discrete behavioural and decision-making entity, whose food and other expenses are managed as a single unit (Chisnall 1975). Hence, the production of post-consumer waste is a household-based activity.

(2) Non-consumer waste derives from household souces, e.g. grass clippings and leaves from the garden, ash from solid fuel heating and so on.

(3) Access to means of waste disposal are centred on the household e.g. the dustbin, the sink disposal unit, the garden compost heap or incinerator, the sewerage system etc.

At the most basic and simple level, the waste generation process may therefore be represented by the expression:

$$W = f(h) \qquad (2.1)$$

where W = the total quantity of waste generated by the household and h = a summary of all factors describing the household.

2.2.4 In the expression above 'waste' is regarded as a single entity. In practice waste is a heterogeneous mix of substances, each deriving from a different aspect of household behaviour. In order to move to a more sophisticated and informative representation of the waste generation process it is essential to distinguish between different types of waste according to the factors which affect their generation. Given a set of waste types 'p' defined in this way and a set of households 'n' then the quantity of waste type k generated by household j can be written as:

$$W_{jk} = (s + t - u)_{jk} \qquad (2.2)$$

where W_{jk} = the quantity of dustbin waste of type k produced by household j

and s = the quantity of post consumer waste of type k produced by household j

and t = the quantity of non-consumer waste of type k produced by household j

and u = the quantity of k waste disposed of via means alternative to the dustbin.

2.2.5 The term describing post consumer waste, 's', can be expanded by examining in more detail the way in which wastes occur as a result of consumption activity. Products yielding some form of satisfaction to the household, together with the wastes associated with those products, enter the household in the form of commodities. The generation of post-consumer waste is therefore a direct corollary of the flow of commodities. If 'commodities' are defined in the narrow sense, as a collection of individual products of specific unit size and brand make, then the waste generated as a result of consumption by the household of a particular commodity is jointly dependent on the weight of waste intrinsic in the commodity and the quantity of the commodity consumed. Given a set of commodities 'm', then the total quality of k waste produced by household j from commodity i is:

$$S_{ijk} = r_{ijk} \cdot q_{ij} \qquad (2.3)$$

where S_{ijk} = the quantity of dustbin waste of type k produced as a result of the consumption of commodity i by household j

and r_{ijk} = the weight of k waste produced as a result of the consumption of each item of commodity i by household j

and q_{ij} = the quantity of commodity i consumed by household j

The sum of k waste produced as a result of the consumption of all types of commodities by household j is therefore:

$$Sjk = \sum_{i =}^{M} r_{jk} \cdot q_j \qquad (2.4)$$

This expression may be substituted into expression (2.2) to derive a general formula for the generation of k waste:

$$Wjk = (\sum_{i=}^{M} r_k.q)_j + t_{jk} - U_{jk} \qquad (2.5)$$

Summing across all waste types, the total quantity of waste generated by household j (W_j) is obtained:

$$W_j = \sum_{k=}^{P} ((\sum_{i=}^{M} w.q)_j + S_j - t_j) \qquad (2.6)$$

2.2.6 The operation of the model can be illustrated by reference to a specific example. The quantity of waste newsprint generated by a household will depend on a variety of factors. Firstly, on the quantity of newspapers, magazines, periodicals etc. bought by the household ('q') and the waste element associated with each item ('r'). For most forms of newsprint the weight of waste will equal the weight of the item since the 'waste element' consists of the item itself in obsolescent form. For other types of commodities the weight of waste will be a fraction of the total weight of the commodity (e.g. the weight of the plastic lid or the glass jar from a jar of coffee). Additional waste newsprint ('t') may be derived from 'non-consumption' sources in the form of a freely distributed weekly advertiser for example. A quantity ('u') of newsprint may be burned on a domestic grate or a garden incinerator, or may be collected separately from the normal refuse. The interaction of all these factors will determine the quantity of newsprint ('W_j') which is finally disposed of via the dustbin.

2.2.7 Having derived a theoretical model in this form, existing consumer theory can be introduced as a basis for hypothesis development. Household consumption behaviour, and to a lesser extent the waste element associated with commodities, is already the subject of a substantial body of consumer theory and intensive market research (e.g. Engel et al 1978, Whalley 1982, OECD 1982a). The factors affecting the ex-post demand for a commodity i (i.e. the quantity actually bought) can be written in shorthand form as:

$$qi = f(Pi; Px,..., Pz; Y; T; r; u)$$

where qi is the quantity of commodity i demanded per period of time; Pi is the price of i; Px,...,Pz are the prices of other goods; Y is money income; T is tastes; r is the rate of interest, particularly relevant in the case of durable goods (see section 2.7); and u is a term which summarises all unknown influences.

2.2.8 In the short term, prices and interest rates may be assumed to be constant. However, income, tastes and 'unknown influences' will vary among households. It is these factors which are particularly important in the context of understanding the differences in waste arisings which occur between households.

The waste coefficient, 'r', will also remain fixed in the short term, and largely fixed among households since it refers to the waste element associated with a specific commodity. In general this is determined at the manufacturing stage, for example the empty can plus ring-pull top from a particular canned beverage. However, 'r' will be subject to variation over time as a result of changes in the use of raw materials, developments in packaging and processing technology and changes in legislation (Briston and Neill 1972). These factors are particularly important in understanding the changes in waste arisings which occur over time.

2.2.9 So far, a theoretical model of household waste generation has been set up and each of the elements of the model has been introduced. The following sections of this chapter examine in detail the factors underlying the waste generation process. The discussion is organised around the three main groups of factors already identified, viz those factors affecting post-consumer waste, those factors affecting non-consumer waste and those factors affecting the household's choice of disposal pathway. The sections concerning post-consumer waste each refer to a particular class of consumer product:

food;
newspapers and magazines;
clothing;
household products and personal care items;
solid fuel;
consumer durables.

2.3 Food Waste

2.3.1 'Food waste' in this context refers to waste generated by the consumption of every type of food and beverage, including its associated packaging. Food products contribute to all types of household waste either in the form of edible leftovers or peelings, rind etc., or alternatively in the form of waste paper, plastic, metal or glass from food packaging. Waste from food accounts for between 50 and 80 percent by weight of average dustbin contents (Merseyside County Council 1981, Rufford 1982). Because of its importance, food waste is given particular emphasis in the discussion of the waste generation process. This section examines the factors affecting the waste coefficient associated with food commodities ('r') and the factors which govern the quantity of food commodities ('q') purchased by the household. The discussion is structured according to the above scheme shown in Figure 2.1 below:

TYPES OF HOUSEHOLD FACTORS			PARAGRAPH
Factors affecting weight of food waste - 'W'	'r'	over time	2.3.2
		between households	2.3.3
	'q'	over time	2.3.4
		between households	2.3.5

Figure 2.1 Framework for the discussion of household factors affecting the generation of food waste

A similar framework is used in the discussion of each category of consumer products (newspapers and magazines, clothing etc). However, the structure is not rigidly applied in all cases since not all types of commodity are subject to variation in all dimensions.

2.3.2 The weight of various types of packaging associated with food ('r') products varies over time according to the technology of the packaging and processing industries, raw material prices, distribution methods (including transport, storage and retail) and manufacturer perception of consumer preferences. Examples of these factors are given below:

(1) <u>Raw Material Prices</u>

Relative changes in the prices of raw materials account for the use of a particular material being discontinued in favour of a close substitute. The shift towards the use of aluminium cans in the beverage industry is a result partly of the cheapness of aluminium as compared to tin/steel (Altenpohl 1980).

(2) <u>Materials Technology</u>

Advances in materials technology frequently result in the substitution of natural materials in consumer products by synthetic counterparts. Plastics have replaced glass, paperboard and metals in many food packaging roles as a result of the development of new polymers (Briston and Neill 1970).

(3) Packaging Processes

Changes in packaging processes can significantly affect package characteristics. The use of the "shrinkwrap" method for example has substantially reduced the weight of packaging used for food products (Briston and Neill 1970).

(4) Transport

Increases in transport costs have increased the emphasis on compactness and "stackability" of packages (Walters 1976).

(5) Storage

The expansion of refrigerated storage facilities in retail outlets and homes has led to changes in package materials and design (Higginson 1982).

(6) Retail Methods

The changeover from counter to self-service retail methods has led to an increase in the importance of the marketing role of packaging with greater emphasis on the styling of packages to influence customer choice between competing brands (Goddard 1975).

(7) Legislation

Legislation connected with food hygiene and the protection of consumer intersts will affect package design. For example the Trades and Descriptions Act 1968 prohibits a manufacturer from making false statements about the volume of goods through the misleading use of packaging.

The weight of food wasted by the household will be largely governed over time by food prices (MAFF 1982). These are influenced in turn by changes in agricultural technology, import controls, farming subsidies etc. The quantity of edible leftovers will also be affected over time by the availability of facilities to prevent deterioration of perishable commodities (refrigerators and deep freezers), and by the use of airtight and resealable containers for packaging.

2.3.3 The weight of packaging associated with specific commodities will be fixed in general since the definition of a commodity, in this context, includes the weight of associated packaging. However, the weight of edible leftovers will vary systematically between households according to household dietary behaviour. Factors affecting dietary behaviour include household size, income, socio-economic group, age, composition and pet ownership (Hanson 1975, Wenlock 1979, MAFF 1982). Specifically, these studies have shown that single person households (in which there is no other household member to take 'first choice' of surplus food) and high income households tend to waste the highest proportions of food in the form of left-overs.

2.3.4 The quantity of food ('q') consumed by households will vary over time both on a seasonal basis and according to longer term trends. Seasonal factors include the availability of seasonal foods and periodic events such as Christmas and annual vacations. In the long term the quantity of food consumed will be determined by food prices and by dietary preferences. Although overall real expenditure on food has remained farily stable since 1950 (Central Statistical Office 1980) there is a national trend in the UK towards more 'cosmopolitan' tastes in food with a concomitant decline in the consumption of traditional foods such as potatoes and meat cuts.

2.3.5 The quantity of food consumed will vary between households according to a complex set of factors including household size, age structure of the household, occupation of household head, leisure activities, commitments outside the food budget, meals eaten away from home, freezer ownership, access to garden and allotment space, level of education and acquired tastes and preferences. These affect:

(1) The total quantity of food consumed by the household.

(2) The choice of specific commodities, including unit size and brand name.

According to an extensive survey of food expenditure carried out in the USA by Crockett (1960), food consumption increases with household size, but less than proportionally with the number of household members. The choice of commodities also varies between households of different size. Single adults living alone spend less than the per capita average on fresh meat and vegetables, and two adult plus children families buy more convenience foods per capita than two adult only households (MAFF 1982). The ratio of weight of packaging to weight of product falls when food is bought in bulk so, all other things being equal, large households are expected to generate less than average amounts of packaging per head. For a constant household size, households with the largest incomes generally spend most on nearly every type of product including seasonal, frozen and convenience foods (MAFF 1982). As a general rule the proportion of income spent on food declines as income rises ('Engel's Law'). Estimates of the income-elasticity of demand for food (i.e. the responsiveness of demand for food to changes in income) fall mostly in the region of 0.5, or relatively inelastic (Crockett 1960). However, for individual commodities the income elasticity may be greater than one (luxury items) or negative (cheap substitutes). Crockett's study of food expenditure in households in the United States suggests that a parabolic relationship exists between food expenditure and age of the head of household. For a given household size and income, food budgets were found to be highest when the head of household was in the age range 45-64 years, and to decline by 10% among very young and very old families. Systematic variations in food expenditure have also been found between households grouped according to tenure, ownership of a deep freeze, 'age of housewife' and 'ethnic origin' (Crockett 1960, MAFF 1982). For example, freezer owners tend to spend more on carcase meat and frozen convenience foods, and less on meat products and canned and 'other' convenience foods. Households in owner-occupied dwellings in general consume the highest levels of fresh meat, vegetables and dairy products, whereas council tenants spend more on processed vegetables, meat products and take-away meals.

2.4 Newspapers and Magazines

2.4.1 Newspapers and magazines account jointly for 12% by weight of dustbin contents and, next to food, represent the second largest component of household waste. Newspapers are disposable and the waste fraction therefore consists of the item itself in obsolescent form. They are also 'perishable' in the sense that they become waste as soon as a more recent edition is published. Choice of newspaper will affect the amount of waste newsprint generated per unit purchased ('r') since different newspapers have different standard sizes (e.g. 'quality papers' are heavier than 'popular press papers'). Each type of newspaper and magazine, including national and local dailies, 'Sundays', general weeklies and monthlies and women's weeklies and monthlies have distinct readership profiles. These are distinguished by socio-economic group, sex, age, occupation and education of reader (JICNARS 1981). For example, the largest proportion of readers of quality newspapers (The Guardian, Telegraph, Times and Financial Times) are in social grades AB whereas the largest proportion of Sun, Mirror and Star readers are in grades C2 and DE. 'Housewives' (women who are married and not economically active) comprise 69% and 67% of readers of 'Woman' and 'Woman's Own' magazines, respectively. Choice of newspaper will therefore vary systematically between households.

2.4.2 The number of newspapers and magazines purchased by households will vary over time according to price (linked to production and distribution costs and size of circulation), competition from other media and educational standards. In 1950, 80% of adults read a national daily newspaper and 90% a national Sunday newspaper. In 1978 the corresponding figures were 72% and 81% respectively. Over the same period the sales of women's magazines, and magazines devoted to politics, gardening and motoring also fell (Central Statistical Office 1980).

2.4.3 The number of newspapers purchased by the household has been found to vary according to household characteristics and to be strongly related to household income. The Family Expenditure Survey (Department of Employment 1982) shows that of households sampled, those in the highest income category spent five times as much on newspapers and magazines as households in the lowest income category.

2.5 Clothing, Personal Care Items and Household Products

2.5.1 It has been estimated that clothing comprises approximately 70% by weight of the textiles category in household waste and therefore 2-3% by weight of all household waste (Boyd et al 1971). Clothing also contributes packaging to the paper and plastics fractions of household waste and to the 'miscellaneous combustible' category in the form of discarded footware. The weight of waste which derives from the consumption of specific types of clothing ('r') changes over time according to the state of packaging technology and trends and fashions in retail e.g. the trend away from boxed and highly packaged shirts to shirts bought 'loose' (Bolen 1982). Although clothing materials have changed quite radically as a result of the development of cheap, synthetic fibres, most clothing is still fabric-based and therefore, by definition, falls within the textile category of waste. The quantity of clothing ('q') purchased by households will vary over time in response to clothing prices (linked to raw material prices and the state of technology in the textile and garment industries) and the durability of clothing products. As a proportion of total household income, expenditure on clothing has fallen by 10% since 1950 according to available data (Central Statistical Office 1980). A detailed study by Hamburg (1960) of household consumption of clothing in the USA found that clothing expenditure varied systematically among households according to household size, income, age structure and sex composition.

2.5.2 Waste from personal care items (e.g. cosmetics, soap, deodorants) and from household products (e.g. washing powder and cleaning agents) was found to comprise approximately 7% by weight of dustbin contents in a study of household waste carried out in the USA (Boyd et al 1971). The main waste materials from these types of products derive from packaging and dispensing containers. The size of the waste fraction ('r') is generally large since many cosmetic and household products are heavily marketed with a strong emphasis on novelty and design of the container. The size of the waste fraction will be governed over time by raw material prices and technology in the packaging and manufacturing industries although, compared with more essential commodities, changes in package design are less likely to be incorporated for functional or economic reasons at the expense of visual appeal or loss of brand identity. One of the most pronounced changes in the packaging of toiletries and household products in recent years has been the growth in the use of aerosols from 164 million units in 1964 to 610 million units in 1970 (Briston and Neill 1972). Other changes include the substitution of plastic tubes for collapsible metal tubes to package products such as toothpaste, and the use of PVCs instead of polythylene for containers of shampoos, detergents etc. The quantity of personal care items and household products purchased varies among households according to household size, income, age and sex composition and marital status (Frank et al 1967). The Family Expenditure Survey indicates that weekly expenditure on toilet requisites and cosmetics in the highest income category is eight times higher than the lowest income category, while spending on soap and cleaning materials is three times as high.

2.6 Solid Fuel

2.6.1 The waste products associated with the consumption of solid fuel are ash and cinder which contribute to the 'fines' fraction of household waste. The characteristics of the redisual produced as a result of burning a fixed quantity of solid fuel ('r') will vary according to the fuel type; for example bituminous coal tends to produce cinder whereas smokless fuel reduces to fine ash. A household's choice of fuel type will therefore affect the characteristics of the waste arisings. In general there has been a shift away from the use of bituminous coal towards the use of anthracite which can be burned in smoke restricted areas (Brown 1969). However bituminous coal is still used on domestic grates in rural areas and in some mining districts where it is still available on a long-established concessionary basis.

2.6.2 Trends in the overall consumption of solid fuel by households ('q') are affected by the relative costs of different energy forms, by legislation, by architectural trends and by amenity standards. Since the implementation of the Clean Air Act 1956 there has been a swing to the use of gas, oil and electricity for heating purposes (Tombs 1979) and this has inevitably resulted in a considerable reduction in domestic coal consumption and a concomitant fall in the quanity of solid fuel residuals in household waste.

Substantial variations in solid fuel consumption also occur on a seasonal basis and according to fluctuations in temperature (seasonal variations in waste arisings are considered in greater detail in Chapter 8).

2.6.3 The consumption of solid fuel will vary between households according to age and design of property, and according to property location with respect to smoke restricted areas. In new dwellings the increased standard of amenity expected has resulted in the use of gas, oil and electricity for central heating. The implementation of smoke control regulations and the higher cost of smokeless fuel in comparison with bituminous coal have encouraged many households previously dependent on solid fuel to convert to alternative forms of heating.

2.7 Consumer Durables

2.7.1 'Consumer durables' are durable or capital goods whose services are not instantly consumed (McCormick 1977). They contribute to household waste via the packaging element and, to a lesser extent, via the products themselves in spent or discarded form. The packaging element is the most important source of waste since, by definition, the products themselves are absorbed into the household inventory. When they eventually become obsolescent, durable products are generally disposed of via second hand or scrap dealers, civic amenity sites or fly tipping. Some smaller durable items however, particularly electrical appliances, may be disposed of via the dustbin.

2.7.2 The weight of packaging associated with specific durable products ('r') will change over time with raw material prices and with developments in packaging technoogy and distribution methods. Two key changes that have occurred in recent years are the replacement of solid board by corrugated board because of the latter's superior performance to weight ratio and the use of polystyrene as a packaging and cushioning material in place of straw and angelica (Briston and Neill 1972). The composition of the durable products themselves has altered under the impetus of the continued need to reduce manufacturing costs, changes in styling to correspond to the designers' perception of consumer preferences and to encourage early obsolescence in previous models, and the pressure of competition from overseas manufacturers (Packard 1960, Whalley 1982). In general, strong lightweight materials such as polymers and aluminium have tended to replace ferrous metals in consumer durables.

2.7.3 In a study of household consumption of durable products Cramer (1962) found that expenditure on durables varied according to household size, income, age of household head and net wealth. Cramer argues that since major durables are indivisible and expensive, current income is unlikely to dominate consumer decisions to the same extent as it does for other commodities. Instead he suggests that consumption is determined by the level of stocks (i.e. wealth). Kish and Lansing (1957) found that the number of domestic appliances bought by a sample of households was related to the stage in the households' 'Family Life Cycle'; for example, the number of households owning TV sets in Kish's sample increased from 5% in the 'young single' stage to a maximum of 20% at the stage of 'married couples with young children' and declined again to 5% in the 'older single' stage. The concept of a 'Family Life Cycle' provides a useful summary of a number of interrelated household variables: age of household members, marital status and presence or absence of children. Since Kish first introduced the concept it has been used in a number of marketing studies (e.g. Wells and Gubar 1966) and has been adopted in the present research as a general indicator of household consumption behaviour (see section 2.11.5).

2.8 Non-Consumer Waste

2.8.1 'Non-consumer waste' comprises any waste material which does not originate from the consumption by the household of external goods and services. It consists mainly of 'garden waste' (e.g. grass clippings, tree prunings, leaves etc), vacuumings and carpet soil, discarded mail, and waste from garden and allotment produce. There is no established body of theory equivalent to consumer theory which can be drawn upon to explain the generation of non-consumer waste. However, a study of household waste carried out in the USA by Richardson and Havlicek (1974) found that the quantity of garden waste generated varied on a seasonal basis, with largest quantities occuring in the spring and autumn and a reduction in quantities in the summer. It is reasonable to assume that access to garden and size of garden (related to geographical and socio-economic factors) and the amount of leisure time available to the household (related to age and occupation of household members) will also govern the amount of garden waste generated. Vacuumings and carpet soil are expected to vary according to property size and to a 'houseproud factor' (possibly related to whether one or both adult members of a household are employed).

2.8.2 Mail is shared jointly by the household in the form of bills and 'mailshots', and is also addressed to individual household members. A fixed and variable component in the quantity of mail is therefore expected in relation to household size. Mail serves both as a means of social and business communications and as a marketing medium. Soliciting by mail is generally targeted towards those households most likely to be interested in and able to afford the product on sale (Douglas 1982). There will also be an element in household and personal correspondence connected with credit arrangements, accounts and subscriptions. A relationship between quantity of mail and household income is therefore hypothesised. Handbills and 'advertiser newspapers' enter the household via the same route as mail but are generally distributed indiscriminantly to all households within an area.

2.8.3 The quantity of garden and allotment produce in the household diet will vary according to season and also according to household income, age composition, type of dwelling and freezer ownership (MAFF 1982). The factors which affect the proportion of this type of food which is wasted have been discussed in section 2.3.3.

2.9 Alternative Disposal Pathways

2.9.1 This section examines the various alternative pathways for the disposal of household waste in addition to the dustbin. These include waste fed to household pets, waste collected for recylcing and waste taken to civic amenity sites. A full list of alternative pathways is given in table 2.1. The extent to which a household uses these waste outlets has clear implications for the quantity of waste disposed of via the dustbin. There is little comprehensive information available in the literature about the flow of waste via alternative pathways. Kneese et al (1970) have developed a theoretical macro-model tracing the flow of residuals from households to the environment, but the flows are not quantified. A number of studies have examined the use of specific waste outlets and the results of these studies are reviewed below.

2.9.2 Wenlock (1979) carried out a study of household food wastage which included an investigation of the quantity of food fed to pets and wild birds. The results of the study indicated that where households kepts pets, particularly dogs, considerable quantities of waste food were fed to the animals. The amount of food diverted to animals, as a proportion of total

Table 2.1 Waste Pathways which Represent Alternatives to the Dustbin for the Disposal of Household Waste

DISPOSAL PATHWAY	TYPE OF WASTE AFFECTED
1. Domestic pets 2. Sink disposal units 3. Garden compost heaps 4. Meals eaten outside the home	Edible leftovers and other putrescible waste
5. Fly tips 6. Civic Amenity sites 7. Second-hand and scrap dealers	Durable goods and clothing
8. Charity collections	Clothing, paper
9. Public litter bins	Newsprint and packaging
10. Bottle banks and other recycling schemes	Bottles, cans and paper
11. Garden incinerators 12. Domestic fires	Combustible waste
13. Sewerage system	Cosmetic and sanitary waste
14. Local authority 'special collection' services	Bulky waste and garden waste

edible leftovers, was found to vary on a seasonal basis from 30% in the winter to 20% in the summer. No statistically significant relationships was found between the amount of food given to animals and household composition, income or region in which the household was located. The quantity of food wasted in this way depended almost entirely on whether the household owned a pet.

2.9.3 Meals eaten outside the house are a means by which waste is effectively diverted from the dustbin. The number of meals eaten outside the house has been found to vary systematically between household according to 'age of housewife', housing tenure and freezer ownership (MAFF 1982). It is also intuitively evident that the number of meals eaten inside the home will increase during vacation periods and school holidays.

2.9.4 A direct alternative to the dustbin for the disposal of putrescible wastes is the sink disposal unit or kitchen grinder. A small scale survey of a block of flats in Bristol equipped with sink disposal units (DoE 1975) indicated that the use of these appliances was generally limited to food wastes comprising between 10 and 15 percent by weight of household waste. Access to sink disposal units is related to dwelling characteristics. They are most frequently installed in newly built properties, particularly private flats where there is an advantage in reducing the amount of putrescent wastes which must otherwise be disposed of via refuse chutes or else carried to ground floor level.

2.9.5 The quantity of waste glass deposited in bottle banks will depend primarily on the location of the household in relation to bottle bank facilities (Lawrence 1981). In regions where bottle banks are sited it has been estimated that they are used to dispose of approximately 8% by weight of all domestic glass (Good 1983). Other factors which affect the quantity of glass disposed of by the household in this way are socio-economic group and the perceived distance of the bottle bank from the home (Kuylen and Van Raaji 1979). It is reasonable to assume that the use of other fixed location recycling schemes (e.g. 'Cash-a-Can') and the use of civic amenity sites will also depend primarily on how accessible they are and on whether the household has the use of a motor vehicle.

2.9.6 Municipal 'special collection' services provide an alternative to the dustbin for the disposal of bulky refuse (i.e. oversize items and building waste) and garden refuse. Policy with regard to the collection of these types of waste and the charges made for the collection services vary between local authorities. Dustbin waste will therefore be affected on a regional basis by the provision and cost of special collection services (DoE 1975). The frequency of waste collection from certain types of dwelling, and the size of refuse container or number of sacks supplied to households, also varies between local authorities (Research Institute for Consumer Affairs 1979). Frequency of waste collection and size/number of disposal receptacles will determine the disposal capacity available to the household at any given time. Available disposal capacity has been shown to affect the quantity of dustbin waste disposed of by the household (Hajek 1981).

2.9.7 Other disposal pathways include public litter bins, the sale of second hand items and garden compost heaps and garden incinerators. No published information has been located on these pathways but certain assumptions can be made concerning their use by households. These assumptions contribute on 'a priori' basis to the research hypotheses concerning household disposal behaviour. It is reasonable to assume that newspapers bought over the counter, during the journey to work for example, are more likely to be disposed of in a litter bin or other public place than newspapers which are delivered to the home. A link is therefore expected between whether or not a household has newspapers delivered and the quantity of waste newsprint in the dustbin. The sale of unwanted or obsolescent household articles for resale or scrap is expected to be related to household income as a result of the relative value attached to the revenue from such enterprise. Lastly the dumping or burning of waste on a garden compost heap or incinerator by the household is expected to vary according to access to and size of a garden or allotment area and the location of the household with respect to smoke control zones.

2.10 Setting the Boundaries of the Research

2.10.1 The preceding sections have set out the conceptual basis of the research and considered evidence of the relationships between waste arisings and household factors. The next stage in the research involves translating the theoretical evidence into a series of explicit research hypotheses which can be tested in practice. There are two fundamental constraints which apply in translating the theory into an empirically testable form. The first is a resource constraint which restricts the scope of the empirical research to a case study of one dimension of the variation in waste arisings, namely the variation between households. This issue is explained fully in paragraph 2.10.2 below. The second constraint is one of feasibility and practicality of hypothesis testing. In order to test hypothetical relationships it must be possible to obtain measurements of the constructs involved. Section 2.11 is therefore concerned with recasting the constructs identified in the preceding theoretical discussion into measurable indicators suitable for empirical analysis.

2.10.2 Four separate dimensions to waste variation were described in the preceding sections:

(1) Variation in waste arisings between households due to factors such as household size and income.

(2) Variation in waste on a regional basis as a result of regional distinctions in factors such as bottle bank location and smoke control zones.

(3) Variation in waste over time on a cyclical basis and events in the religious and commercial calendars.

(4) Long term trends in waste arisings due to such factors as advances in technology and the substitution of raw materials.

2.10.3 Because there were limits to the time and resources available for the research, it was not possible to investigate all of the dimensions of waste variation. In practice, available resources confined the experimental phase of the research to a cross-sectional survey of waste arisings within one region and a single time period. In effect, the research was able to test only a 'partial model' of waste arisings. In the partial model all factors apart from those which vary between households were held constant. The hypotheses taken forward to the experimental phase of the research therefore relate exclusively to factors which account for variations in waste arisings between households. The assumptions of constancy in both regional and temporal factors are maintained throughout the experimental and analytical phases of the work. In Chapter 8, however, these assumptions are relaxed and ways of extending the model are considered to enable it to accommodate regional, seasonal and long-term changes in waste arisings.

2.11 Development of Testable Hypothesis

2.11.1 In order to empirically test a research hypothesis, the elements of the hypothesis must be measurable in practice. This section describes how the 'general constructs' identified in the theoretical investigation were recast into 'measurable indicators'. Two separate tasks were involved:

(1) The definition of categories of waste in such a way as to reflect as closely as possible the process of waste generation.

(2) The selection and scaling of appropriate indicators for household factors.

These two tasks are discussed in successive sections below.

2.11.2 Categorisation of Waste

Fifteen categories of household waste were defined by grouping waste substances according to one of two criteria:

(1) The function of the parent commodities of post-consumer type waste.

(2) The origins of non-consumer type waste.

A number of additional criteria were also taken into account in the definition of the waste categories. These criteria relate to practical considerations which, although strictly unconnected with the theoretical issues being considered in this Chapter, are briefly described at this point in order to explain the system of categorisation adopted:

(1) A system of waste categorisation which is too rigidly defined in terms of the factors underlying waste generation is likely to neglect the needs of users of waste information. The physical properties of household waste which are of specific interest in the context of waste management are therefore reflected in the waste categories.

(2) For practical experimental purposes it must be possible to discriminate between types of waste during hand-sorting. The waste categories were therefore designed to be 'easily identifiable'.

(3) To allow cross comparison of the research findings with the results of other research the fifteen waste categories have been devised so that they can be expressed in terms of the 'standard eight' categories used in conventional UK surveys of household waste.

A complete description of the fifteen categories is given in Table 2.2.

Table 2.2 Description of the Fifteen Household Waste Categories

WASTE CATEGORIES	DESCRIPTION
ORGANIC kitchen matter	organic materials arising from the preparation/discard of food e.g. peelings, rind, bone, scraps.
ORGANIC garden matter	non-food vegetable matter e.g. grass cuttings, weeds, prunings.
PAPER small scrap and packaging	e.g. discarded tissues, paper bags, stationery.
PAPER newsprint	e.g. newspapers, magazines, books.
PAPER cardboard	e.g. shirt backing, cardboard tubes and boxes.
METALS ferrous	e.g. steel/tin cans and aerosols.
METALS non-ferrous	e.g. aluminium drink cans and foil.
TEXTILES	woven and fabric based goods e.g. clothing, carpet off-cuts, rag.
GLASS	broken and whole glass packaging containers e.g. bottles, jam jars.
PLASTIC film	e.g. plastic bags, film wrap.
PLASTIC dense plastic	moulded plastic items e.g. plastic bottles, cosmetic cases
MISCELLANEOUS combustible (unclassified debris, ambiguous and compound items)	rubber, laminates, leather, wood, electrical cord, plugs and light fittings etc.
MISCELLANEOUS non-combustible	crockery, rubble etc.
PERNICIOUS ITEMS	garden chemicals, paints, solvents, pharmaceutical products, batteries, detergents etc. plus respective containers
FINES < 2cm	material smaller than 2cm in diameter.

The conventional 'vegetable and putrescible' category has been subdivided into kitchen and garden waste, a division which reflects the distinct sources of organic material. 'Paper and board' has been broken down into newsprint, cosmetic and sanitary paper together with stationery and packaging scrap, and cardboard which comprises paperboard and fibreboard from cartons and outercases. Plastic film is classified separately from dense moulded plastic to distinguish wrapping material associated mainly with food from empty household product containers such as detergent bottles (although the distinction is blurred by the fact that some foods are sold in dense plastic containers e.g. cooking oil). The division of ferrous and non-ferrous metals reflects to some degree the difference between food tins and beverage cans. This detailed compositional breakdown is designed to be relevant to the needs of users of waste information while at the same time providing a basis for the prediction of waste arisings.

2.11.3 Selection and Scaling of Measurable Indicators for Household Factors

Household factors were scaled and, where appropriate, measurable indicators were selected against three criteria:

(1) Preservation of 'construct validity' through faithful representation of theoretical constricts.

(2) Practicability and feasibility of obtaining data on the indicators.

(3) Consistency of the indicators with existing household survey data (to allow ultimate grossing up of a statistical waste arisings model).

A comprehensive list of the household factors hypothesised to be related to waste generation is given in Table 2.3. Those factors which can be measured directly are marked with an asterisk (*). Other factors which can only be measured in proxy are considered below.

2.11.4 Information on the incomes of individual households is difficult to obtain for reasons of confidentiality. Five surrogate measures of income were therefore used in the research; property type and size, tenure, car owenership and socio-economic group. These are linked to household income via housing status, prestige, lifestyle and financial position (Gittus 1972). The measures themselves also act as surrogates for other household factors (e.g. 'property type' for 'access to garden') and are themselves independently related to waste generation.

2.11.5 The age structure of households was measured in terms of a composite variable already referred to in the context of expenditure on consumer durables (section 2.7), the Family Life Cycle. Households were assigned to groups corresponding to stages in the Family Life Cycle according to a number of separate criteria: age of family members, marital status and the presence or absence of children. It therefore represents a useful and concise summary of several different

Table 2.3 Hypothesised Relationships Between Household Characteristics and the Generation of Household Waste

HOUSEHOLD CHARACTERISTICS	SURROGATE MEASURES	CLASS OF CONSUMER PRODUCT INFLUENCED	CATEGORY OF HOUSEHOLD WASTE INFLUENCED
Household size* Household income Number of working adults* Number of males/females* Age structure of the household Age of domestic adult*	Property type Propersty size Housing tenure Socio-economic group Car(s) owned 'Family Life Cycle'	Food Newspapers and magazines Clothing Personal care items Household products Consumer durables	Kitchen waste Garden waste Scrap paper etc Newsprint Cardboard Ferrous metals Non-ferrous metals Textiles Glass Plastic Film Dense plastic Misc. combustible Misc. Non-combustible
Type of Food retail outlet frequented for food/ frequency of shopping trips Sink disposal unit owned* Domestic pets owned*	Frequency of shopping trips for food	Food	Kitchen waste
Mode of newspaper purchase*			Newsprint
Type of domestic heating* Location with respect to smoke control zone*		Solid Fuel	Garden waste Newsprint Cardboard Misc. combustible Fines
Access to Garden or allotment area*	Property type		Kitchen waste Garden waste

household characteristics as well as being a undimensional measure of age. The descriptions of stages in the Family Life Cycle were derived from Wells and Gubar (1966):

(1) The bachelor stage: young single people.

(2) Newly married couples: young, no children.

(3) The 'full nest' I: young married couples with dependent children.

(4) The 'full nest' II: older married couples with dependent children.

(5) Older married couples with no children living with them.

(6) The 'Solitary Survivors': older single people.

(7) Undefined households.

2.11.6 Other household characteristics were scaled to be as far as possible consistent with recognised and established systems of categorisation. For this purpose, detailed reference was made to a number of existing systems of social and economic classification (Hoinville and Jowell 1971, Office of Population Censuses and Surveys 1971 and 1980, DoE 1982). A full breakdown of the categories of socio-economic variables used in the research is shown in the reproduction of the household waste survey questionnaire form (Chapter 4, Figure 4.2).

2.11.7 A complete diagrammatic summary of the research hypothesis is given in Table 2.2. The table shows the underlying household factors; the proxy measures used to represent household factors (where appropriate); the classes of consumer product to which the factors are related, and the categories of waste which are the end product of the process.

2.12 Conclusions

This chapter has achieved several important objectives in the context of developing a theoretical understanding of the process of household waste generation. Firstly, the household has been established as the basic unit of waste generation. This is a fundamental tenet on which the research is predicated. Secondly, the chapter has set out a theoretical model which establishes a scientific basis for the investigation of how waste arises. Thirdly, the key factors which underlie the generation of household waste have been identified through extensive reference to available literature and existing research on household consumption behaviour. Fourthly a purposive system of waste categorisation has been developed which both reflects the waste generation process as well as taking account of the practical interests of users of waste information. All these developments have been combined in the form of a set of explicit, testable research hypotheses which form the basis for subsequent phases of empirical analysis and statistical modelling. These are described in Chapter 4.

The following chapter considers in detail the practical needs of information users and their implications for the development of a waste arisings model which will be of value in practical waste management contexts.

CHAPTER THREE

PRACTICAL DEMANDS AND CONSTRAINTS ON THE DEVELOPMENT OF A METHOD FOR HOUSEHOLD WASTE ESTIMATION

3.1 Introduction and Aims

3.1.1 It has already been established that the purpose of the research reported here is, inter alia, to develop a practical method for estimating household waste arisings. Clearly if this is to be done it is necessary to examine in detail the practical needs for information on household waste arisings in order that the method developed in the research is tailored to meet these needs.

3.1.2 In the practical context of waste management there is a considerable diversity of interest in information about household waste arisings, stemming from the diversity of the 'industry' of waste management itself. For example, the industry may be divided into public sector authorities (national government, county disposal authorities, district collection authorities) and also into different private sector interests (disposal site operations, designers and constructors of plant and equipment such as collection vehicles and waste incinerators). Each of these sections has its own demands for information on household waste arisings, and each sector is also subject to certain practical constraints. Clearly it would be difficult to develop a method which could simultaneously meet all the needs of the various interest groups. However, in accordance with the stated objectives of the research, an attempt has been made to organise and structure the different needs for information and to draw from this generalised conclusions that can act as a set of specifications for the development of a practical waste estimation method.

3.1.3 The above process is reported in this chapter in three sections. In section 3.2 the needs for information and the constraints operating on the diverse sections of the waste management industry are reviewed. This is essentially a catalogue of practical needs and limitations. In section 3.3 there is a discussion of the appropriate unit of geographical area for which information on wastes should be provided and the appropriate time period for this information. In section 3.4 there is a discussion of the most appropriate way of categorising the constituent components of household waste in order that household waste is described in a form most appropriate to the wide ranging needs of the wastes industry. In section 3.5 these points are summarised in a conclusion which in effect sets the practical design specifications for the wastes estimation method, the development of which is described in the remaining chapters of this thesis.

3.2 Information Needs and Practical Constraints Within the Wastes Industry

3.2.1 This section is organised under four sub-headings. The first section introduces the administrative and organisational framework within which UK waste management decisions are made. The second section describes the specific contexts in which information on household waste arisings can make a useful contribution to the decision making process. In the third section the importance of information on household waste quantity and composition is evaluated and in the fourth section the practical constraints under which the wastes industry operates are discussed.

Structure of the Wastes Industry in the UK

3.2.2 The waste management industry in the UK has a diverse structure. In England the responsibility for wastes management is divided, with disposal controlled by the county or metropolitan county councils and collection controlled by the districts or metropolitan borough councils. In Wales and Scotland both collection and disposal are the responsibility of the district councils. The task of collecting and disposing of household waste may be carried out either by local authority personnel or by contract labour. Generally, plant and equipment for waste handling and treatment are supplied by private manufacturers, and private contractors are engaged to design and construct waste transfer and disposal facilities. Local authorities may also employ the services of private wastes management consultants to provide information and advice.

3.2.3 The main Act of Parliament governing wastes management in Britain is the Control of Pollution Act (CoPA) 1974 which places a duty on local authorities to ensure that all arrangements for the disposal of controlled waste are adequate and also requires waste disposal authorities to conduct waste disposal surveys and to prepare and update waste dispoal plans (see section 3.2.11). County councils in England and Wales are also required to produce structure plans while the district councils may produce local plans. These affect waste disposal principally with respect to land use. Any proposal to site a disposal plant or landfill site must conform to the general strategy of the structure plan. In addition, any waste disposal facility is controlled by normal planning procedures which may restrict its design and use. Waste management in Britain is also subject to the directives and recommendations of the European Council. Waste management policy at the European Community level is based on the following principles:

- to reduce the volume of wastes and nuisances resulting from disposal.

- to save and re-use the raw materials and energy which may be recovered (Commission of the European Communities 1982).

A variety of different organisations and interest groups are therefore involved in the wastes management process. The following sub-section considers the contexts in which the quantity and composition of household waste is of interest to each of those groups.

Decision making Contexts in which Information on Household Waste Arisings has a Potential Application

3.2.4 Decision making for waste management consists of two basic types:

(a) Political planning

(b) Technical decision-making.

While the distinction between the two is not always clear in practice, political planning generally includes national legislation and policy directives together with local government plans and is carried out by political decision makers, often elected representatives. Technical decision making involves the day-to-day operation of waste management facilities and is carried out by design engineers and professional waste disposal officers. Information on the quantity and composition of household waste has an important role in both types of decision-making. Specific examples are given below to illustrate the way in which the characteristics of household waste impinge on waste management decisions in each of the four key areas of the wastes industry namely:

- waste collection, storage and pre-treatment

- waste disposal
- design and construction of waste plant and equipment
- design of policy measures to curb waste production/disposal

Implications of Waste Quantity/Composition for Waste Collection, Storage and Pre-treatment

3.2.5 The quantity and composition of household waste arisings will have a direct bearing on waste collection, storage and pre-treatment in a number of ways:

(1) Paatero (1981) has shown that the relative efficiencies of alternative forms of waste transport vary according to the quantities of waste being transported. In addition, certain specialised types of waste transport system (e.g. pipeline conveyance) are suited only to particular types of waste such as those with small particle size or high compressability.

(2) It has been argued (Higginson 1965) that waste composition should be taken into account in the choice of transport units, and specifically that less robustly constructed transport units with lighter unladen weights should be used for less dense waste, with a consequent saving in price, maintenance and fuel costs. Other aspects of the design of transport units affected by waste characteristics include the capacity of the units and the incorporation of facilities for power compression and dustless loading.

(3) Waste quantity and composition interact with factors such as housing density and street layout to determine the optimum deployment of manpower and vehicles in the design of waste collection rounds (Jackson et al 1975). Changes in waste characteristics will also have a bearing on the choice of collection method (kerbside collection, step, sack etc.) and on team size and on the number of vehicle loads per day.

(4) Changes in waste quantity and composition will affect the appropriate design of facilities for waste storage. Higginson (1965) suggests that 'any change in the yield and composition of refuse has an immediate effect on the ... size and shape of bins and containers, ... refuse chutes and chambers'. This assertion is particularly relevant to the design of communal disposal facilities and to refuse bunkers at disposal and transfer sites.

Implications of Waste Quantity/Composition for Waste Disposal

3.2.6 The characteristics of household waste have implications for waste disposal in a variety of respects:

(1) The most appropriate disposal method for a particular location (or equally the most appropriate location for a particular disposal method) will depend, among other factors, on the quantity and composition of the waste.

Table 3.1 summarises the criteria recommended by the Commission of the European Communities for the rejection of unsuitable disposal options. The list of criteria includes the minimum quantity of waste arising within the disposal catchment. The table indicates, for example, that incineration with heat recovery is an unsuitable option when the quantity of waste from the disposal catchment is consistently low (less than 150 tonnes/day) or is subject to high seasonal fluctuation, in which case building and manning a plant to meet peak demand would mean that for part of the year men and equipment would be underemployed. The economics of waste disposal are also sensitive to waste composition. Incineration becomes more efficient the lower the initial density of the waste and the higher the proportion of combustible materials. Section 3.4 in this chapter contains a detailed discussion of the specific properties of waste which have a bearing on the efficiency of waste disposal.

(2) Part of the task of waste management involves the commitment of current resources to meet future needs. Forward planning of disposal capacity and disposal options requires the forecasting of future changes in waste quantity and composition. The time horizons involved in forward planning are discussed in section 3.3.5.

Table 3.1 Criteria for the Rejection of Unsuitable Disposal Options (adapted from CEC 1982)

Waste Management Activity / Criterion for rejection of disposal option	Conventional Tipping	Crushing and Tipping	Composition and Tipping	Composting	Incineration	Incineration with Energy Recovery	New Methods of Mechanical Separation
Minimum waste	20-30 t/day	20-30 t/day	50-60 t/day	Slow: 20-30 t/day Accelerated: 30-40 t/day	30-40 t/day	150-250 t/day	No reliable data available
Non-availability of a suitable tipping site	Reject	Reject	Reject				
Prohibitive cost of reject inert material	Reject						
No market for steam or electricity						Reject	
No market for compost				Reject			
Production of waste varies greatly depending on season					Unsuitable	Unsuitable	Unsuitable
High reliability required							Reject
No market for special recoverable materials							Reject
Non-availability of a highly skilled staff or workforce				May be considered		Reject	Reject

KEY: [ ] = Possible

(3) The management of disposal plant can benefit from information about the characteristics of the waste feedstock. To accommodate changes in waste characteristics, waste arisings may be rerouted between disposal facilities or fine-tune adjustments may be made to, for example, the drying of waste for fuel or to the speed of conveyors, separators and furnace grates (Barton 1981, Poll 1982).

(4) Information about the type of waste arising is a prerequsite for monitoring the discharge of potentially harmful substances to the environment (e.g. chemical residues from insecticides and pharmaceutical products and combustion products from certain plastics and metals).

Implications of Waste Quantity/Composition for the Design of Waste Plant and Equipment

3.2.7 Household waste represents the 'raw feedstock' for plant and equipment designed for waste handling and treatment. Waste quantity and composition will therefore directly affect the design specifications (i.e. capacity, power, operating speed, tolerances and temperature and corrosion resistance) and performance ratings of conveyors, compactors, crushing equipment, separators, furnaces, pollution control equipment etc. (Douglas and Birch 1977, Porteus 1977, Grubbs and Coulombe 1978, Bonomo 1980, Jackson 1980, Barton 1981). Kalika (1968) has derived a series of coefficients which relate variations in waste composition to the design of incineration equipment and specifically to the optimum flows of combustion air and cooling water. The process of mechanical separation and recovery of waste is sensitive to small changes in waste characteristiscs, and obtaining the best yield and grade of recovered product depends on matching the design of the separation equipment to the characteristics of the waste feedstock (Buekens 1981).

Implications of Waste Quantity/Composition for the Design of Policy Measures

3.2.8 Policy measures may be used to curb waste production or control its disposal for a number of reasons, for example, to protect public health and the environment, to conserve finite supplies of raw materials or to attenuate the cost of waste collection and disposal. Depending on the desired effect of the policy measure and the type of waste which the policy maker seeks to control the measure may take a variety of forms; examples are legislation, fiscal penalties or incentives, production or import quotas, guidelines for product design (such as the removal of aluminium collars from bottles to aid glass recycling or the design of containers which are crushable or biodegradable), and restrictions or levies on waste collection. In order to design and target the measure effectively it is necessary to be precise about the type, quantities and origins of the waste. Consequently there is a need for a detailed body of information on waste arisings.

The Relative Importance of Information on Waste Arisings in Waste Management Contexts

3.2.9 The value of information on waste arisings is as a decision making aid to reduce the risk of sub-optimal decisions. However, the characteristics of waste arisings represent only one consideration among a set of considerations which govern the choice between alternative waste management decisions. The importance of waste quanity and composition in relation to other factors (e.g. interest rates or political acceptability) is difficult to measure precisely since the various decision making contexts have never been examined in detail. Wilson (1981) recognises the significance of waste quantity and composition in waste management planning but does not evaluate its relative importance against other factors. The level of detail and accuracy of waste information which is useful is certain to vary according to the specific nature and context of the waste management problem. For example if landfill has a distinct cost advantage over alternative forms of disposal, then the characteristics of the waste are likely to have little bearing on the choice of disposal method. However if cost differences between disposal options are marginal, or if the problem is one of selecting the most suitable location for a predetermined type of disposal facility then questions of waste quantity and composition become more prominent. South Yorkshire County Council's Waste Recovery Plant was originally planned for location at Barnsley, but analysis of Barnsley's waste showed that the ash content was too high and the paper content too low for economic recovery and the site was subsequently moved to Doncaster (Surveyor 1979).

3.2.10 The most powerful arguments for improved waste information derive from evidence of problems that have occured through lack of adequate information at the planning stage. Unforeseen qualities of plastic in London's refuse were partly responsible for the technical problems which disrupted the operation of the Edmonton incinerator during the early 1970's (Porteus 1977, Surveyor 1977). Levels of waste from the catchment of Coventry's Waste Reduction Unit proved to be 25% lower than anticipated when the plant was inaugurated. Only by importing refuse from Warwickshire was the West Midlands County Council able to meet its contractual obligations to supply industrial heat from the incinerator to the industrial client (Municipal Engineering 1977). The WMCC's disposal plan concedes that:

> 'current local and national statistics are not of sufficient accuracy to be precise about fluctuations in domestic waste arisings '
> (West Midlands County Council 1980)

Lack of appropriate information is also a problem in the context of policy making. A recurring issue in the debate on packaging and waste management concerns the absence of reliable data on the precise nature and extent of the packaging component of waste. An OECD report on the problem of non-returnable beverage containers (OECD 1978) observes that 'Data for solid waste generation is not very precise ... Furthermore data on the quality of beverage containers in solid waste is usually estimated from production data ...'. Production data cannot distinguish between the containers which eventually become dustbin waste, recycled waste or litter and data of this type is therefore inadequate as a basis for policy formulation.

3.2.11 The importance of information on waste arisings is recognised in the Control of Pollution Act 1974. Section 2 of the CoPA which came into force in 1978 places a duty on Waste Disposal Authorities to prepare waste disposal plans setting out the arrangements needed for the disposal of controlled waste arising in, or transported into, the authority's area. Specifically Section 2 of the CoPA requires that the plan should include information on the kinds and qualities of controlled waste for which the authority is likely to have to provide.

3.2.12 The benefit to local authorities in cost terms of waste information is difficult to assess. Davies (1983) argues that since expenditure by local authorities on the collection and disposal of waste approaches £600 millions per annum, each reduction in costs of just one percent (whether achieved through improved operating efficiency, better waste disposal planning, enhanced yields from resource recovery or by other means) gives a potential annual saving of £6 million. If more detailed and accurate information on the quantity and composition of waste can enable these efficiencies to be achieved then the case for improving current estimation methods is fully vindicated.

Practical Constraints on the Wastes Industry and their Implications for Waste Estimation

3.2.13 In order to be acceptable to the wastes industry any type of aid to decision making must take account of the constraints under which the industry operates. These constraints are set by finite limits to expenditure, time and manpower skills. A new approach to waste estimation must therefore be both cheap and simple. It has been observed (Leclere et al 1980) that professional waste officers tend to prefer 'rule of thumb' techniques for information gathering and to resist complex or highly sophisticated procedures. 'Simplicity' therefore implies conceptual clarity. In order to break tradition with conventional methods of waste estimation any new approach should also be no more expensive than current methods and should preferably represent an advance in cost terms. 'Cheapness' therefore implies working within the existing budgets which the wastes industry allocates for this type of data collection. The need for simplicity and cheapness are accentuated by the fact that waste estimation is not a 'once only' activity but a process which is likely to be carried out on a regular basis in order to incorporate new information and to take account of advancing time horizons in forward planning.

3.3 Appropriate Spatial and Temporal Units of Waste Information in the Context of Wastes Management

3.3.1 The first part of this chapter has introduced the diverse range of practical applications for information on waste arisings. The next section addresses the question of the appropriate units of waste quantity and units of time which are of interest in each of the key areas of waste management. It has been established that the basic unit of household waste generation is the dustbin. This represents a single week's waste from an individual household. In certain specific contexts data is required in the form of waste per household per week (e.g. in the design of household disposal receptacles and in the calculation of a waste collection levy). However most other aspects of wastes management involve dealing with waste in bulk and data on individual households is too disaggregate for practical purposes. Translating 'dustbin data' into a useful form therefore involves some upward level of aggregation. The appropriate level of upward aggregation increases in a hierarchical fashion from waste collection, through waste disposal to policy making.

3.3.2 In the context of waste collection the most fundamental unit of area is termed the 'tour'. This is the block of work which will fill one vehicle and typically it is made up of 300 to 600 households. Tours are organised into days (usually two per day) and days are then amalgamated into weekly rounds or beats. Each of these areal units is of interest to collection authorities, to contract waste collection companies and to the manufacturers of waste collection equipment.

3.3.3 Waste disposal facilities are fed from specified catchment areas. The size of the catchment area depends on the capacity of the disposal facility; typically it will vary from 2000 to 130,000 households. Units of waste quantity in these orders of magnitude are therefore of interest to waste disposal authorities and to manufacturers of disposal plant and equipment.

3.3.4 Policy making bodies are generally concerned with relatively low levels of resolution corresponding to their administrative or legislative areas. These may vary in size from the local area (e.g. a local bye-law controlling the deposit of certain items in dustbins) to the international level (e.g. codes of practice for environmental protection agreed by international treaty). The wide range of levels of aggregation at which waste information is required for different purposes indicates the need for a method of waste information which is 'geographically flexible' in order to be applicable at a variety of spatial scales.

3.3.5 In addition to providing information on current waste arisings, a comprehensive approach to waste estimation should also be capable of estimating waste arisings at future points in time. The appropriate time horizon will depend on the specific context in which the waste information is being applied. The Department of the Environment's guidelines for the preparation of waste disposal plans by local authorities recommends that the plans should include 'a projection of future increases or decreases in the types and quantities of waste over the next 10 years'. (Department of the Environment 1977). The recommended forecast period for local government structure plans, which include policy on waste disposal, is 15 years. The appraisal of investment decisions may require a perspective on changing waste characteristics over the lifetime of a particular item of capital expenditure. An indication of the expected lifespan of capital items relevant to waste disposal is given by the permitted government repayment periods on local authority borrowing. These are:

60 years for land
40 years for buildings and civil engineering works
20 years for machinary, plant etc.
10 years for vehicles
(Wilson 1981)

The financial appraisal of an investment in an incinerator for example may therefore amortize different parts of the capital over periods of 10 to 60 years. The wide range of time periods of interest in different waste management contexts indicates the need for a method of waste estimation which can forecast over a variety of time horizons.

3.3.6 To summarise, this section has outlined the need for a method which can both estimate and forecast waste arisings at varying levels of geographical aggregation and at varying points in the future. This need for flexibility reflects the diverse responsibilities and interests of the different sections of the wastes industry.

3.4 The Design of a System of Waste Categorisation to Take Account of the Practical Needs of the Wastes Industry

3.4.1 The purpose of this section is to establish a system of waste categorisation which takes account of the practical needs of the users of information on waste arisings. The categorisation is developed through a detailed discussion of the properties of waste which have practical significance for waste management decisions. The discussion is structured around each of the key waste management activities namely:

- collection, storage and pre-treatment
- disposal
- policy making

Properties of Household Waste Significant in the Context of Waste Collection, Storage and Pre-treatment

3.4.2 The volume of household waste (as opposed to its weight) is the most important property of waste in relation to its collection, storage and pre-treatment. It is the volume of waste which dictates the capacity of collection vehicles, storage receptacles and reception hoppers and which also determines the relative advantages of using power compression in vehicles, and the benefits obtained from pre-treamtnet techniques such as baling and pulverisation. Certain other characteristics of waste also affect the efficiency of the pre-treatment process. Tests on self-sustaining bales reported in Solid Wastes (1975) found that bales fell apart when either:

(1) the paper and cardboard content of the waste was too low.

(2) the content of tins was too low.

(3) the ash content exceeded 15%.

(4) the content of glass was higher than 5%.

(5) the moisture content exceeded 30 to 35%.

Properties of Household Waste Significant in the Context of Waste Disposal

3.4.3 The composition of waste affects landfill practice through the following mechanisms:

(1) the minimum standard of the basic hydrogeological conditions and any necessary modifications to the site (e.g. lining with impervious material).

(2) rate of void depletion.

(3) after-use of the site.

Toxic or otherwise harmful materials e.g. medical or veterinary waste, paints and solvents, acids and heavy metal residues from batteries and garden or agricultural chemicals may either be leaked from a landfill site into the surrounding environment or may remain unattenuated when the site is reclaimed for agricultural, recreational or dwelling purposes. The level of biodegradable materals in household waste will affect the extent of tip settlement and the rate of gas generation. Large quantities of plastic may act as a barrier to drainage. The advantages of untreated landfill over methods involving volume reduction are greatest when the density of the waste is high (LGORU 1972). Low waste density may favour the use of initial baling or pulverisation.

3.4.4 The characteristics of waste which are of interest in relation to waste incinerators are those which affect:

(1) rate of burning and furnace capacity.

(2) composition of gases generated and residue after incineration.

(3) corrosion or other damage to the incinerator.

(4) volume reduction obtained.

The initial density of the waste and the proportion which is combustible are important parameters since incineration is, in effect, a volume reduction process and the greatest volume reductions are obtained for low density combustible waste. The calorific value and mositure content of the waste influence the rate of burning and the furnace capacity of incinerator units (Neissen and Chansky 1970). Waste materials which are irritant or damaging to the combustion process include heavy items such as spark plugs and nails which cause mechanical damage (Corey 1969), thermoplastics which may clog incinerator grates (Higginson 1971) and polychlorated biphenyls (PVC's) which generate chlorine compounds which cause corrosion of refractory linings and boiler tubes (where incineration is combined with heat recovery).

3.4.5 The most important characteristics of waste in the context of waste recycling and recovery are:

(1) The levels of secondary materials in the waste or the potential yield of reprocessed material (e.g. Refuse Derived Fuel).

(2) The presence of irritant or unwanted substances in the waste which are likely to be detrimental to the recovery process or which may contaminate the recovered product.

Salvage schemes rely on a steady flow of paper, glass, metals or textiles (Jackson 1980). A high proportion of combustible material is required for the economic production of refuse derived fuel while the manufacture of compost, animal fodder and biogas are based on the organic fraction of household waste (Bonomo 1980). The types of materials which inhibit recovery processes are fine materials such as ash which lead to dust problems and increased wear and tear on machinery, and damaging items such as strands of electrical cable or banding wire (which tend to clog machinery) and flammable and explosive substances and oversize items. Substances which contaminate or lower the value of the recovered product include ash and moisture which reduce the available energy of refuse derived fuel (Sheng and Alter 1975) heavy metals from house dust which make food waste unsuitable for animal fodder (Tjell et al 1981) and large quantities of fragmented glass which will contaminate compost made from waste (Commission of the European Communities 1982).

Properties of Household Waste Significant in the Context of Policy Making

3.4.6 It is difficult to talk presumptuously and in general terms about the types of waste which are of interest in a policy making context. However, certain groups of waste products can be singled out through having been the subject of proposed or actual regulatory controls in the past:

(1) Packaging wastes. These have been criticised for adding excessively to the costs of waste collection and disposal, for aesthetic blight from windblown material, for air pollution from waste combustion and

for damage to combustion equipment and for the loss of potentially valuable raw materials e.g. as a result of the disposal of non-returnable beverage containers (Darmay 1969, OECD 1978, Waste Management Advisory Council 1981).

(2) Garden waste etc. Various types of 'non-domestic materials' including garden waste, DIY waste and builder's rubble are given special consideration by collection authorities. Depending on the policy of the authority this type of waste may be either collected together with other dustbin waste, collected on demand either free of charge or at a cost to the householder, or not collected at all (Department of the Environment 1975).

(3) Toxic or otherwise harmful substances. Provisions exist under the Control of Pollution Act 1974 for the abatement of substances in household waste which may cause a danger or a nuisance. Waste Disposal Authorities have the task of monitoring and in some cases bringing prosecutions under the Act for the deposit of these types of waste (see for example incidents reported by Pearce 1982).

3.4.7 The implications of the preceding discussion of the various properties of household waste of interest in waste management contexts are drawn together in Table 3.2. A summary of the range of different waste management activities is

Table 3.2 Summary of Characteristics of Household Waste Relevant in Wastes Management Contexts

Characteristics of Household Waste \ Waste Management Activity	Untreated Landfill	Initial Volume Reduction and Landfill	Incineration	Incineration with Energy Recovery	Composting/ Animal Fodder	Recovery of Secondary Materials	Production of Refuse Derived Fuel	Collection, Storage and Pre-treatment	Design of Policy Measures
Weight	✓	✓	✓	✓	✓	✓	✓	✓	✓
Volume (density)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Combustible fraction			✓	✓			✓		
Calorific Value			✓	✓					
Moisture content			✓	✓	✓	✓	✓		
Organic content					✓	✓	✓		
Paper content						✓			
Glass content					✓	✓			
Metals content						✓			
Textiles content						✓			
Plastics content	✓	✓	✓	✓		✓			
'Fines' content						✓			
Pernicious items	✓	✓	✓	✓	✓	✓	✓	✓	✓
Packaging fraction									✓

given on the vertical axis and the corresponding relevant waste characteristics are shown on the horizontal axis. Not all waste characteristics are self-determined. Some can be inferred from other, more fundamental characteristics, allowing the number of different parameters of waste which need to be measured in practice to be condensed. An indication of the density of different types of waste (and hence their volume) may be obtained from standard tables (e.g. Bond and Straub 1973). LGORU (1969) have used linear regression to derive an equation connecting the overall bulk density of the waste with the proportion by weight of 'paper' (other waste components were found by LGORU to have little effect on bulk density because they tend to be absorbed into the voids created by paper/cardboard items). Both the calorific value and the moisture content of waste can be inferred from information on the physical composition of the waste (see Higginson 1971, Bond and Straub 1973).

3.4.8 Given the practical requirements for a system of waste categorisation, the type of standard categorisation system appropriate for this research may now be considered. In this context there are further considerations to be taken into account in addition to the practical requirements outlined in Table 3.2 above. The first of these is the need for a classification that will reflect the theoretical basis of household waste generation (the subject of Chapter 2 of this thesis). In essence, this amounted to a need to be able to trace the product or purchased commodity within the waste categorisation, and a detailed specification for this was set out in Table 2.1. The second additional consideration in choosing an appropriate waste categorisation system is the question of measurability. The research has been designed to incorporate an experimental phase which involves sorting and analysis of household waste to provide the empirical data for testing and calibrating a waste model. The categorisation system adopted must therefore be measurable from the practical point of view of the handsorter. Thirdly, to allow cross-comparison of the results of this research with other surveys of household waste, there is a need to be able to relate the system of categorisation with the conventional systems of waste categorisation already in use.

3.4.9 Taking all of these factors into account, a 15 category categorisation of household waste was designated as the basis for this research. These 15 categories have been chosen in such a way as to meet as many of the above demands as possible. A full listing of this categorisation has already been presented (Table 1.3 in Chapter 1) and is used henceforth in this thesis as the basis for the development of a method of waste estimation.

3.5 Conclusions

3.5.1 This chapter has discussed the question of the appropriate form and content of waste information to satisfy the practical demands of the wastes industry. The main conclusions of the Chapter can be drawn together in the form of a set of specifications for the design of a practical method of waste estimation:

(1) The method should be simple and cheap and should represent an advance over existing methods in terms of cost saving as well as in terms of the quality of waste information which it provides.

(2) The method should be geographically flexible in order to be effective at varying levels of geographical aggregation. Different sectors of the wastes industry have responsibilities and interests at a range of different spatial scales and the method should be adaptable to each of these applications.

(3) The method should provide a basis for forecasting waste arisings at different points in the future.

(4) The method should provide information on the physical properties of waste which have direct relevance to decisions in waste management.

(5) The method should be sufficiently sensitive to discriminate between the consequences of alternative options and courses of action in waste management.

These 'design specifications' provide the basis for the development in subsequent chapters of a practical and comprehensive method of waste estimation.

CHAPTER FOUR

EXPERIMENTAL AND ANALYTICAL METHOD

4.1 Introduction and Aims

4.1.1 In order to test the research hypotheses set out in Chapter 2 of this thesis, an extensive programme of fieldwork was carried out followed by a programme of data analysis. The purpose of the fieldwork was to collect information on the socio-economic characteristics of households and information on their waste arisings. The fieldwork results were analysed in three phases; firstly the hypothesised relationships between household characteristics and household waste arisings were tested; secondly alternative forms of household based waste arisings model were developed; thirdly the a method for estimating waste arisings on an area basis was devised. This chapter is concerned with the methodology of the experimental and analytical phases of the research. It explains the rationale underlying the research methodology and describes in detail the conduct of the fieldwork. It also sets out the logical basis for the techniques used in the analysis of the results.

4.1.2 The separate sections of the chapter are organised in the following way. Section 4.2 explains the purpose of each stage in the experimentation and analysis. It includes an overview of the research methodology in relation to the research objectives. Sections 4.3 and 4.4 are concerned with how the fieldwork was designed and carried out. Specifically, section 4.3 explains the basis for the sample size and structure, and section 4.4 reports the practical aspects of the fieldwork including the administration of the household questionnaire and the collection and analysis of waste samples. Section 4.5 contains a summary and a conclusions.

4.2 Rationale for the Research Methodology

This section explains the rationale for each stage in the experimentation and analysis. The research methodology was designed within a framework of decision criteria based on the research objectives. Table 4.1 serves to reiterate the research objectives and to provide an overview of the relationship between research objectives and research method. The main stage-by-stage discussion of the research methodology is preceded in this section by a summary of the circumstances of the fieldwork and data analysis. This provides a practical perspective for the subsequent discussion.

Summary of the Practical Aspects of the Fieldwork and Data Analysis

4.2.2 The programme of fieldwork was carried out in two phases; firstly a two month period of household surveillance during which information on the socio-economic characteristics of households was gathered through doorstep interview; secondly a three month period of collection and analysis of household

TABLE 4.1 Summary of the Relationship between Research Objectives and Research Method

RESEARCH OBJECTIVE (SEE CHAPTER 1, SECTION 1)	STAGE IN EXPERIMENTATION	
	Practical	Analytical
Objective 1: to establish the relative sizes of the systematic and random elements of variance in waste arisings.	Repeated weekly analysis of household waste and exercise to determine measurement error.	Determination of systematic element of variance.
Objective 2: to compare waste arisings from households of different types.	Cross-sectional survey of socio-economic characteristics and waste arisings of 1277 households.	Hypothesis testing using one-way analysis of variance
Objective 3: to explain and predict waste arisings through a household based model.		Use of multivariate techniques for model building.
Objective 4: to develop an area based waste estimation method suitable for waste management needs.		Development of computerised technique for data retrieval and analysis.

waste arisings. The fieldwork was carried out between July and November 1982. During this period 1440 households were interviewed and the dustbin contents from 1277 of the households were analysed, some repeatedly over a number of weeks. A team of five interviewers, eight refuse sorters and one loader were employed to assist with the project. The work was funded jointly by the Institute of Waste Management and the West Midlands County Council (WMCC). Financial support and co-operation were obtained from the WMCC on a contract basis. The contractual arrangement required that the WMCC be supplied with information on the quantity and composition of household waste within the catchment area of a proposed plant to manufacture Refuse Derived Fuel (RDF). The location for the RDF plant had been previously determined as the site of the disused Castle Bromwich municipal incinerator in Birmingham, and the fieldwork was therefore carried out within a ten kilometer radius of the site as shown in Figure 4.1. A covered area for the storage and sorting of household waste, together with refectory facilities and ablutions were provided at the incinerator.

4.2.3 The practical phase of the experimental work was followed by a six month period of data coding, file creation and data analysis on the University of Aston HARRIS computer. In fulfilment of the contractual obligation with the West Midlands County Council an estimate was made of the quantity and composition of waste arisings within the Birmingham Metropolitan Borough using the data collected during the survey. The results of the experimental work were first

Fig. 4.1 Map of the West Midlands County showing the area covered by the household waste survey

presented to a conference of the Institute of Wastes Management in September 1983 (see Appendix D).

Objective 1: Determination of Systematic and Random Variance in Household Waste Arisings

4.2.4 This sub-section explains the experimental method used to respond to the first objective of the research, namely to establish the relative sizes of the systematic and random elements of the variance in waste arisings. The basic unit of waste measurement referred to in this context is the dustbin. The dustbin represents the quantity in weight of waste generated by a discrete member of a population (one household) over a discrete period of time (one week). A hypothetical population of households will yield a distribution of measurements of waste arisings with a mean $\overline{x}$ and a variance σ^2. The variance can be attributed to a number of different sources. Firstly variance in waste arisings that occurs as a result of substantive differences between households. This element of variance may be termed systematic variance. A second element of the variance can be attributed to the fact that households do not produce identical types and amounts of waste from week to week within one 'season' (a season being the unit of time over which systematic influences on waste arisings are hypothesisted to be stable). The effect of week to week variation is to increase the error in using a sample of one dustbin to represent the mean seasonal waste arisings from the household. This element of the variance is therefore termed sampling error. In addition, because it is impossible in an imperfect world to measure precisely the quantity of waste generated by a household, an element of measurement error will also contribute to the total observed variance in waste arisings. Together, sampling error and measurement error constitute the random variance component in the distribution. The size of the systematic element of variance in relation to random variance is fundamentally important since it determines the potential accuracy of a household waste arisings model based on household characteristics.*

4.2.5 Assuming that each element of the variance is normal and independent, the total observed variance σ^2_p of a distribution of measurements of waste arisings may be summed according to the principle of r.m.s. addition of variances:

$$\sigma_p^2 = \sigma_l^2 + \sigma_j^2 + \sigma_t^2$$

where σ_p^2 = total observed variance

and σ_l^2 = systematic variance

and σ_j^2 = sampling error

and σ_k^2 = measurement error

---

* It is necessary to acknowledge, however, that part of the systematic variance will be inherently unpredictable, being due to the particular oddities and idiosynchracies of behaviour peculiar to all households.

The importance of the above relationship lies in the fact that the proportion of variance which is systematic can be calculated on the basis of known sampling error and measurement error. Part of the practical phase of the experimental work was therefore designed to determine both sampling and measurement error. Week-to-week variation in household waste arisings (sampling error) was measured by analysing 219 individual batches of waste taken from 73 different households over a period of three weeks. Measurement error was determined in a separate experimental exercise which involved the repeat sorting of batches of waste by different teams of operators. The normality and independence of both types of variance element were later confirmed. An account of the experimental procedure used to determine measurement and sampling error is given in sections 4.4.3 to 4.4.4 of this chapter and also in Appendix A. The results are presented in Chapter 5.

Objective 2: Comparison of Waste Arisings from Different Types of Household

4.2.6 The comparison of waste from different types of households (distinguished by their socio-economic characteristics) represents a process of hypothesis testing. If waste arisings from households grouped according to a particular characteristics are shown to be significantly different, then the hypothesis connecting that characteristic with waste generation is confirmed. As a means of investigating waste arisings from households of different types questionnaire information and measurements of waste arisings were collection from a sample of 1277 households. The significance of each of the household characteristics covered by the questionnaire in discriminating between waste arisings was examined using a statistical technique called one way analysis of variance. A full account of the survey method is given in section 4.3.5. The use of the analysis of variance technique and the results are described separately in Chapter 6.

Objective 3: Development of a Household based Waste Arisings Model

4.2.7 Two forms of waste arisings model were developed through an iterative process during which the model structure was progressively refined in response to feedback about the model's performance. The details of model development are described in Chapter 6. This section is concerned specifically with the provisions made in the design of the experimental procedure for estimating the parameters of the relationships between household characteristics and waste arisings. Because a large number of household characteristics were being examined simultaneously the sample was designed in such a way as to avoid confusing the effects of the different household characteristics on waste arisings. Sample observations were therefore distributed according to the principles of factorial design as a means of experimental control (the principles of experimental design and factorial control are discussed in greater depth in section 4.3.5).

The aim was to isolate the household characteristics from each other as far as possible in order to determine their separate effects on waste arisings. Subsequent analytical procedures included the use of multivariate statistical techniques in two different roles:

(1) To control by statistical means correlations between household factors which it was not possible to control by experimental design.

(2) To derive 'synthetic variables' to more closely represent the basic constructs underlying the household factors.

Objective 4: Development of an Area-Based Waste Arisings Model

4.2.8 The problem of developing an area based method of waste estimation was approached through a computerised technique which combined information from the household waste survey with data from the national census. The technique was developed in two stages. In the first stage waste generation coefficients were derived for types of household on which comprehensive information was available from the census. In the second stage the appropriate census information was retrieved giving the distribution of households within pre-selected areas. By combining the data on the number of households of different types within each area with the corresponding waste generation coefficients, area estimates of waste quantity and composition were obtained. The technique was applied to two test zones of contrasting size in order to demonstrate its spatial flexibility. A full account of the methodology and results of this exercise is given in Chapter 7.

4.3 Experimental Design

4.3.1 This section describes in detail each aspect of the survey of waste arisings including:

(a) the form of the household questionnaire and the waste analysis proforma.

(b) the size and structure of the main survey (i.e. the number of households sampled and the way in which sample households were selected).

(c) the timing of the survey.

(d) the design of the subsidary surveys to measure week-to-week variance and measurement error.

Form of the Household Questionnaire and Waste Analysis Proforma

4.3.2 The questionnaire used in the household survey is reproduced in Figure 4.2. The questions relate directly to the set of household characteristics hypothesised to be associated with waste arisings. These have been comprehensively listed in Chapter 2, Table 2.1. Questions 3 to 6 on the questionnaire are concerned with property type, tenure, household size and socio-economic group, and were used as a basis for structuring the survey (see section 4.4.2). Households were either included or excluded from the survey depending on their response to these questions. Distributed together with each questionnaire was a letter explaining to householders the purpose of the survey and providing an assurance of confidentiality in respect of both information provided in the interview and details of the contents of their dustbins.

4.3.3 The waste analysis proforma is reproduced in Figure 4.3. The waste catagories on the proforma are identical to those derived on the basis of theoretical and practical considerations and listed in Table 1.3 of Chapter 1. Both the questionnaire sheet and the waste analysis proforma were precoded to allow information to be transfered directly to computer filestore.

Principles of Sample Control

4.3.4 The main survey was designed with the aim of calibrating the hypothesised relationships between waste arisings and household characteristics. The identification of causal relationships in a complex setting is confronted by a number of difficulties. These derive from the problem of disentangling the separate chains of cause and effect between those variables

UNIVERSITY OF ASTON HOUSEHOLD WASTE SURVEY

date____________________
time____________________
name____________________

case	☐☐☐☐	1- 4
card in case	☐	5
1.ADDRESS		
multiple dwellings: no. / name / ct./ho.	☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐	6-20
street: no. / name / rd./av.	☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐	21-35
ward	☐☐☐☐☐☐☐☐☐☐	36-45
2.SMOKE CONTROL ZONE	☐	46
3.PROPERTY TYPE		
detatched	☐	47
semidetatched	☐	48
terraced	☐	49
multioccupancy ('bedsit')	☐	50
purpose-built multistorey	☐	51
4.TENURE		
owner-occupied	☐	52
council rented	☐	53
housing association	☐	54
other rented	☐	55
5.OCCUPATION OF HOUSEHOLD HEAD		
economically active:		
A professional	☐	56
B intermediate	☐	57
C1 skilled non-manual	☐	58
C2 skilled manual	☐	59
D partly skilled	☐	60
E unskilled	☐	61
unemployed A-C1	☐	62
unemloyed C2-E	☐	63
economically inactive:		
retired	☐	64
student	☐	65
other inactive	☐	66
6.TOTAL HOUSEHOLD SIZE	☐	67

case	☐☐☐☐	1- 4
card in case	☐	5
7.SOLID FUEL HEATING and/or domestic grate	☐	6
8.SINK DISPOSAL UNIT OWNED	☐	7
9.NUMBER OF BEDROOMS (1 2 3 4 5 6+)	☐☐☐☐☐☐	8-13
10.DOMESTIC PETS OWNED	☐	14
11.DEEP FREEZE OWNED	☐	15
12.MILK DELIVERED	☐	16
13.MODE OF NEWSPAPER PURCHASE	☐	
none	☐	17
counter sale	☐	18
delivered	☐	19
14.WEEKLY MAGAZINE PURCHASED	☐	20
15.NUMBER OF CARS (1 2 3+)	☐☐☐	21
16.SHOPPING TRIPS FOR FOOD		
once a fortnight or less	☐	22
once a week	☐	23
twice a week	☐	24
3-5 times a week	☐	25
daily	☐	26
17.HOUSEHOLD COMPOSITION		
0- 4 years	☐	27
5-15 years	☐	28
16-24 years	☐	29
25-34 years	☐	30
35-44 years	☐	31
45-59 years	☐	32
60-65 years	☐	33
65+ years	☐	34
18.NUMBER OF MALES	☐	40
19.NUMBER OF FEMALES	☐	41
20.AGE OF DOMESTIC ADULT (16-24, 25-34, 35-44, 45-59, 60+)	☐ ☐ ☐ ☐ ☐	42-46
21.SECOND ADULT EMPLOYED (no, p/t, f/t)	☐ ☐ ☐	47-49

Fig. 4.2 Questionnaire used in the household waste survey

UNIVERSITY OF ASTON HOUSEHOLD WASTE SURVEY

date ______________________

operators ______________________

case number	☐☐☐☐	1- 4
number of days waste	☐	5
1.TOTAL waste arisings	☐☐!☐☐	6- 9
2.ORGANIC kitchen waste	☐☐!☐☐	10-13
3.ORGANIC garden waste	☐☐!☐☐	14-17
4.PAPER scrap stationery, packaging etc.	☐☐!☐☐	18-21
5.PAPER newsprint	☐☐!☐☐	22-25
6.PAPER cardboard	☐☐!☐☐	26-29
7.METALS ferrous	☐☐!☐☐	30-33
8.METALS non-ferrous	☐☐!☐☐	34-37
9.TEXTILES	☐☐!☐☐	38-41
10.GLASS	☐☐!☐☐	42-45
11.PLASTIC film	☐☐!☐☐	46-49
12.PLASTIC dense	☐☐!☐☐	50-53
13.MISCELLANEOUS combustible	☐☐!☐☐	54-57
14.MISCELLANEOUS non-combustible	☐☐!☐☐	58-61
15.PERNICIOUS items	☐☐!☐☐	62-65
16.FINES <2cm	☐☐!☐☐	66-69

description of pernicious items

Fig. 4.3 Waste analysis proforma used in the household waste survey determined on a priori basis (independent variables) and those determined on a posteriori basis (dependent variables). Blalock (1973) identifies a number of specific impediments to the process of causal inference:

(1) Spurious relationships where variables x and y are associated, but through the effect of an intermediate variable.

(2) Correlated 'independent' variables where variables correlated with a dependent variable may be correlated amongst themselves and act as a single 'syndrome'.

(3) Measurement errors which act as additional unknowns.

(4) Interaction effects where the strength or nature of a relationship is dependent on the state of the variables.

(5) Reciprocal causation where x affects y and y affects x.

4.3.5 The basic logic of the controlled survey is to isolate the separate effects of the independent variables on the dependent. This is achieved by distributing observations evenly among all possible combinations of independent variables according to the principles of factorial design. However, there are practical problems in the construction of a perfectly balanced factorial design.

(1) Difficulties arise in isolating two variables which are correlated. The intercorrelation will show up in the uneven distribution of cases. If there are unequal numbers of cases in the subgroups of the factorial design, then the weighted means in any one dimension will reflect both the effect of that dimension and the hidden, spurious effect of other factors disproportionately represented in the sub-group.

(2) As the number of independent variables and the number of levels associated with each variable increases, the number of combinations of variables which must be sampled increases exponentially.

It was not possible, because of the sheer number of independent variables in the study, to control by experimental design every possible factor that could remotely account for correlations with waste arisings. The sub-groups in the experiment were therefore matched on property type, tenure, household size, and economic activity (see section 4.3.6). The search for causal relationships was pursued further in the analytical phase of the work during which multivariate techniques (n-way analysis of variance, multiple regression and principle components analysis) were used to take account of the remaining intercorrelations within the survey data.

Practical Survey Design

4.3.6 The sample survey was based on twenty four types of household designated by the cross-classification of four variables: property type, tenure, household size and economic activity (a dichotomous variable derived by collapsing the occupation of the head of household into active and inactive categories). The four variables selected to control the sample were those hypothesised to be most strongly associated with waste generation. Where intercorrelation was anticipated between two variables however, only one of the pair was included in the set of control variables (e.g. the sample was not controlled by 'type of domestic heating' because of the likely coincidence between this variable and 'property type'). The research budget allowed 60 observations to be taken from each type of household, a total of 1440 observations. It was not possible to determine in advance the sample size necessary to give a predefined standard error of estimate of waste arisings since no prior information was available about the variation in waste arisings between individual households. The sample size therefore represented the maximum that available resources would permit.

Timing of the Survey

4.3.7 Samples of household waste were collected and analysed in the Autumn period between September and November and the results of the survey were therefore representative of that season. However, previous studies of household waste arisings (e.g. Higginson 1965, 1981) suggest that waste arisings in the Autumn most closely reflect the annual average.

Design of the Survey to Measure Week-to-Week Variance

4.3.8 A random subsample of 73 households were selected from the main household sample. Repeat measurements of waste arisings from these households were compared over three consecutive weeks to give an indication of weekly variance. There was no means for determining absolutely the appropriate sample size to give a predefined standard error and the number of households surveyed therefore again represented the maximum that available resources would allow.

4.4 Practical Conduct of the Questionnaire Survey and Method of Waste Collection and Analysis

4.4.1 This section reports the practical and logistical aspects of the questionnaire survey and the procedure for waste collection and analysis. It also describes briefly the experimental exercise carried out to determine the extent of measurement error involved in the handsorting process.

Conduct of the Questionnaire Survey

4.4.2 The questionnaire survey served three simultaneous functions:

(1) Structuring of the survey. Sample quotas of different household types were filled on the basis of questions contained in the questionnaire.

(2) Obtaining information on households' socio-economic characteristics.

(3) Obtaining householders' consent to analyse their dustbin contents.

Interviews were conducted at random locations largely within the North East sector of Birmingham. The residential districts in this sector were sufficiently mixed to include a diverse range of household types. Studies of Birmingham's urban ecology (e.g. Edwards 1970) confirmed this. At the same time the size of survey area was kept within manageable boundary limits in order to conserve two key expense elements of the survey: interviewer's travel and the cost of transporting waste to the sorting area. Sample quotas for each household type were divided among a team of five interviewers who searched to find the correct number of observations to fill the quota controls. Interviewing was carried out in evenings and at weekends as well as during working hours to avoid biases arising from the ommission of households with two working adults. Once collected, the information on the pre-coded questionnaire forms was transferred on to computer filestore.

Collection of Waste Samples

4.4.3 One week's waste was collected from each of the households covered by the questionnaire survey. Problems of gaining access to dustbins in certain cases and problems in synchronising the survey collections with the regular weekly collections reduced the number of waste samples finally analysed from a potential figure of 1440 to 1277. Three consecutive weekly samples of waste were taken from a subsample of 73 households to measure week-to-week variation in waste arisings. The collection and analysis of waste samples was carried out within a three month period immediately following the programme of doorstep interviews, but householders were not aware in which week their waste would be analysed. Strict control was exercised over the type of waste material collected. Only waste which was normally removed by the regular weekly collectors was taken for analysis. This included all household waste held in dustbins or dustbin liners or refuse sacks, but specifically excluded garden material (except where it was mixed with other household waste), oversized objects or other unbagged items. Where households were equipped with communal disposal facilities as opposed to individual dustbins, householders were asked to dispose of one week's waste in a specially provided refuse sack. All samples of waste were labelled with a pre-coded tag to enable the waste to be identified later and details of the contents matched against information on the household's socio-economic characteristics.

Analysis of Waste Samples

4.4.3 The analysis of the waste samples was carried out by a team of eight refuse sorters. Each sample was emptied from its labelled sack and sorted into its component categories on a static, 2cm mesh screen (the conventional method of mechanical sieving was rejected because the separation obtained was too crude and because the process tended to swell the 'fines' category by breaking down friable waste material). The weight of each component category was measured on a spring balance and recorded on a proforma sheet (see Figure 4.3) together with the household's individual identifier code. All of the waste samples were in an 'as discarded' condition as opposed to a compacted state. The distinction is important since the characteristics of household waste tend to change through being subjected to power compression in a collection vehicle (Niessen and Chansky 1970).

4.4.4 Inevitably there were some practical difficulties during handsorting. The most common problems were:

(1) Loss of materials, particularly flyaway substances such as dust and ash or liquids and semi-liquids that

were difficult to contain or else adhered to screens and containers.

(2) Interpretation of ambiguous materials, particularly laminates and compound items and materials that were physically similar but functionally different (e.g. certain synthetic fabrics and plastics).

(3) Physical separation of mixtures of materials such as assemblies of components or else substances of a fine or coagulant nature which were too thoroughly blended to allow complete separation.

Errors due to inconsistencies in handsorting and weighing were measured by comparing the results of separate analyses of the same batch of waste samples by different teams of operators. In total, 10 samples of waste were analysed by 4 different teams of operators. The findings are given in Chapter 5. A complete account of the waste analysis procedure (including the exercise to determine measurement error) together with a detailed description of the contents of each of the waste categories is given in Appendix A.

4.5 Conclusions

4.5.1 This Chapter has described the underlying rationale and the practical aspects of the experimental phase of the research. The experimental procedure was designed to obtain information to respond to the four research objectives, viz, to measure the systematic variance in waste arisings, to compare waste arisings from different household types, to build a household waste model and to develop an area-based method for estimating waste arisings. The core of the experimental phase of the research was a cross-sectional survey of 1277 households to obtain information both on their socio-economic characteristics and on their waste arisings. Subsidiary surveys were also carried out to measure the week-to-week variation in dustbin contents and the extent of measurement error.

4.5.2 In the subsequent analytical phase of the research techniques for data retrieval and analysis were used in a number of contexts:

(1) To test the significance of household characteristics in discriminating between waste arisings.

(2) To derive 'synthetic variables' to represent the basic constructs underlying the household characteristic.

(3) As a means of statistical control.

(4) To derive information on the distribution of household types within preselected areas as a means of obtaining area estimates of waste arisings.

Chapters 5, 6 and 7 of the thesis, report the results of the experimental and analytical phases of the research.

CHAPTER FIVE

DESCRIPTION AND INTERPRETATION OF THE RESULTS OF THE HOUSEHOLD WASTE SURVEY

5.1 Introduction and Aims

5.1.1 This chapter presents the findings of the experimental phase of the research in which the waste arisings from 1277 households were individually handsorted and weighed. It also describes the results of the subsidary surveys carried out to measure week to week variance in waste arisings and to determine measurement error. The statistical analysis of the experimental results is designed to respond directly to the first research objective, namely to quantify waste variation between households and to distinguish between systematic and random variation.

5.1.2 The main body of the chapter is divided into four sections. Section 5.2 compares the findings of the survey carried out in this research with the findings of other UK waste research. Similarities and discrepancies between surveys in the quantity and composition of waste in an 'average dustbin' are discussed. Section 5.3 describes the statistical distributions of the 1277 individual samples of household waste. The results are expressed firstly in terms of absolute weight and secondly in terms of percentages of total waste. The characteristics of the distributions of each of the component categories are described in relation to the composition of the categories.

Section 5.4 examines the extent to which the distributions of measurements of waste arisings conform to theoretical distributions, and the implications for subsequent data analysis. Section 5.5 apportions the variance in waste arisings between households into (a) variance due to substantive differences between households and (b) variance as a result of sampling and measurement error. The key findings of the chapter are summarised in the concluding section.

5.2 Summary of the Survey Results and Comparison with the Findings of other Wastes Research

5.2.1 Table 5.1 summarises the results of the household waste survey in respect of the mean weight of total waste, the mean weights and percentages of the individual components and the range in measurements recorded for each waste category. For the purposes of comparison household waste is classified both in terms of (a) the system of categorisation developed specifically for the research (b) the standard UK Department of the Environment system of categorisation. The table shows that on average one sixth of the DoE 'vegetable and putrescible' category consists of garden refuse; the remainder is organic kitchen waste. Newsprint comprises approximately half of the traditional 'paper and board' category and represents the weight of about ten daily newspapers. The remainder of the paper and board category is made up of cardboard and scrap paper which constitute around a quarter each. The division of 'metals'

Table 5.1 Summary of the Component Categories of Household Waste (based on 1277 samples)

WASTE CATEGORIES Research Categorisation	DoE Categorisation	WEIGHT OF WASTE ARISINGS (kg per household per week) MEAN	(RANGE)		PERCENTAGE OF TOTAL ARISINGS	
Total Household Waste		10.1	(0.0-54.1)	10.1	100.0	
Components						
1 Kitchen Waste	Vegetable and Putrescible	3.20	(0.0-24.9)	3.85	31.6	38.0
2 Garden Waste		0.65	(0.0-20.9)		6.4	
3 Scrap Paper etc	Paper and Board	0.71	(0.0-10.1)	2.50	7.0	24.7
4 Newsprint		1.24	(0.0-13.0)		12.3	
5 Cardboard		0.55	(0.0- 8.9)		5.4	
6 Ferrous Metals	Metals	0.62	(0.0-11.8)	0.70	6.1	6.9
7 Non-ferrous metals		0.08	(0.0- 5.9)		0.8	
8 Textiles		0.32	(0.0-19.6)	0.32	3.2	
9 Glass		0.99	(0.0-13.4)	0.99	9.8	
10 Plastic film	Plastics	0.28	(0.0- 6.3)	0.51	2.7	5.0
11 Dense plastic		0.23	(0.0- 6.9)		2.3	
12 Miscellaneous combustible	Miscellaneous	0.53	(0.0-12.4)	0.78	5.2	7.6
13 Miscellaneous non-combustible		0.25	(0.0-21.7)		2.4	
14 Fines <2 cm		0.47	(0.0-18.6)	0.47	4.6	

into ferrous and non-ferrous largely reflects the difference between food tins and aluminimum drink cans. By weight the tins predominate, although in terms of volume the two are more equal. 'Plastics' are evenly divided between plastic film and dense plastic. Two-thirds of the combined 'miscellaneous' categories consist of combustible materials (e.g. wood offcuts, footwear), the remainder is miscellaneous non-combustible waste (ceramics, rubble etc).

5.2.2 Table 5.2 compares the survey results with two other sources of data on waste arisings: firstly the DoE national statistics compiled from local authority returns; and secondly the results of a large-scale household waste survey carried out jointly by Merseyside County Council and the Industry Committee for Packaging and the Environment (Merseyside County Council 1981). The basis for comparison is limited because of the decline in detailed surveillance carried out in the UK, particularly since the divorce of the responsibility for waste disposal from the responsibility for waste collection which accompanied the reorganisation of Local Government in 1974. The Table shows that, in terms of percentage composition, the differences between the Birmingham-based research, the results of the Merseyside survey and the national returns are relatively small. The levels of vegetable/putrescible waste and paper/board waste recorded for Birmingham are somewhat higher and lower respectively compared to the other results. There are two alternative explanations for these discrepanies, in addition to the self-evident hypothesis of regional

Table 5.2 Comparison of the Results of the Household Waste Survey with the Results of Other Contemporary UK Surveys

WASTE CATEGORIES	SURVEY		
	Birmingham 1982	Merseyside 1980	D.o.E. 1980
Vegetable and Putrescible (%)	37.9	35.6	25
Paper and Board (%)	24.5	29.2	29
Metals (%)	6.7	6.5	8
Textiles (%)	3.1	2.8	3
Glass (%)	9.6	8.9	10
Plastics (%)	5.0	3.9	7
Fines 2 cm (%)	4.4	10.1	14
Unclassified (%)	7.5	3.1	4
TOTAL WEIGHT Kg/h'hold/week	10.1	11.2	11.0

differences. Both explanations reflect differences in methodological approach. Firstly, waste from Birmingham was handsorted 'as discarded' as described in section 4.4.3. Waste from Merseyside and from the local authorities who contributed to the DoE returns was sorted after compaction in a collection vehicle, according to DoE recommended practice. Compaction results in the migration of moisture between waste categories, largely from vegetable matter into paper and textiles, and this can result in significant losses and gains in the weights of the respective categories. The moisture content of paper for example has been found to increase from 8.0% to 24.3% between the household and the disposal site (Niessen and Chansky 1970). The discrepancies may also be due to the more detailed and meticulous approach to handsorting adopted in the practical phase of this research. Organic kitchen material is frequently wrapped in paper or plastic and superficial separation (of the type achieved by a mechanical screen for example) will tend to positively bias the paper and plastic categories and detract from the organics category as a result.

5.3 General Description of the Distributions of Household Waste Arisings

5.3.1 This section discusses the statistical distributions of the measurements of household waste from the main survey of 1277 households. The purpose of examining the distributions of the waste measurements in detail is twofold. Firstly they are of intrinsic scientific interest in their own right. No previous known study has plotted the distributions of waste measurements from individual households in this way. Secondly, the characteristics of the distributions have a direct bearing on the type of statistical analysis which the data can stand. The question of whether the sample distributions conform to theoretical distributions and the implications for subsequent data analysis is addressed in section 5.4. This section describes the distributions in general terms and attempts to relate their characteristics to the underlying composition of the waste categories. The distributions represent measurements of household waste expressed in two different ways:

(1) In terms of absolute weight (total waste and 15 component categories).

(2) In terms of percentages of total waste (15 component categories).

Distribution of Measurements of Total Weight of Waste Arisings

5.3.2 The statistical distribution of 'total waste' can be summarised in terms of the following parameters:

Mean ($\overline{x}$)	=	10.11 kg
Standard deviation (σ)	=	6.48 kg
Coefficient of variation (CV)	=	64.1%
Minimum	=	0 kg
Maximum	=	54.1 kg
Sample size (n)	=	1277

A frequency plot of the distribution in the form of a computer produced line chart is shown in Figure 5.1. The distribution is located around a mean of 10.11 kg and a median of 8.40 kg. The displacement of the mean to the right of the median is an indication of positive skew which results from the greater spread of waste measurements at the high end of the distribution. The median weight of waste coincides with the capacity of a standard sized refuse sack. The coincidence can be interpreted in two ways, either as good sack design or else as an indication that disposal behaviour is conditioned partly by the size of the waste receptacle (see section 2.9.6). The spread of the distribution measured in terms of the coefficient of variation* is 64%. The cumulative frequency distribution in Figure 5.2 shows that three-quarters of households in the sample generated between 2 kg and 14 kg of waste per week. Only 2% generated in excess of 30 kg per week and only 2% generated no waste at all. The largest quantity of waste recorded from a single household was 54 kg, or more than five times the mean.

Distributions of Individual Waste Components Measured in Terms of Weight

5.3.3 The distributions of the component categories of household waste exhibit certain common features and certain differences. This section compares the distributions and attempts to

---

* The coefficient of variation is a measure of relative dispersion. It expresses the standard deviation as a percentage of the mean.

```
EACH * REPRESENTS   5 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
  0.00       23   *****
  2.00       83   *****************
  4.00      149   ******************************
  6.00      216   ********************************************
  8.00      193   ***************************************
 10.00      163   *********************************
 12.00      134   ***************************
 14.00       95   *******************
 16.00       56   ************
 18.00       55   ***********
 20.00       31   *******
 22.00       26   ******
 24.00       12   ***
 26.00       13   ***
 28.00       10   **
 30.00        3   *
 32.00        2   *
 34.00        4   *
 36.00        1   *
 38.00        2   *
 40.00        2   *
 42.00        0
 44.00        1   *
 46.00        1   *
 48.00        0
 50.00        1   *
 52.00        1   *
```

Fig. 5.1 Frequency distribution of total waste arisings (kg/hh/wk)

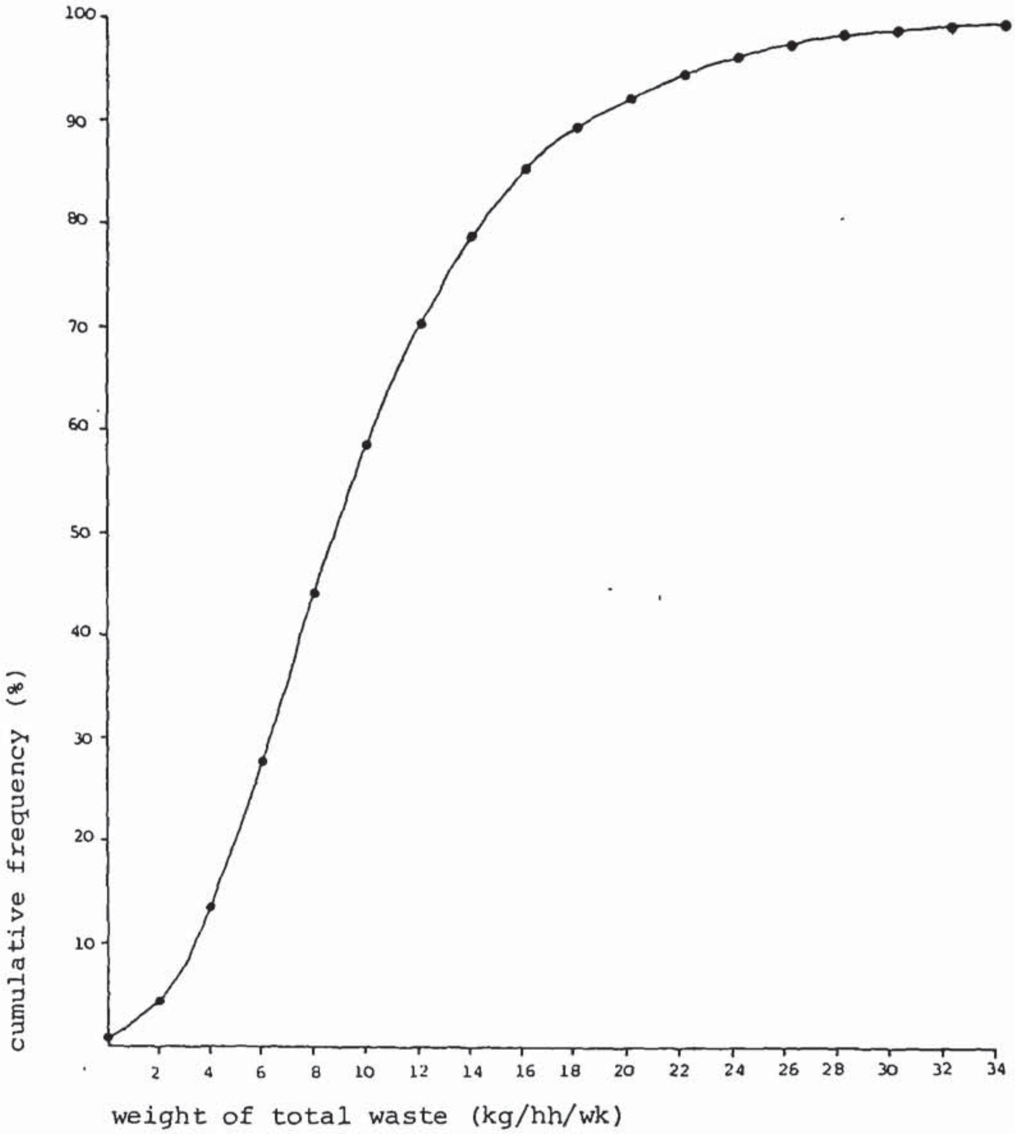

Fig. 5.2 Cumulative frequency distribution of total waste arisings

account for their characteristics partly in terms of the of the underlying composition of the waste categories (for a full description of the statistical parameters of each distribution accompanied by frequency plots, see Appendix B). As a basis for discussion the distributions are combined into six groups shown in Table 5.3. The discussion in this section is organised around the three fundamental statistical parameters of distributions on which the groupings are based, namely central tendancy, dispersion and shape.

5.3.4 The mean weights of the various component categories of household waste have been described in section 5.2.1 and Table 5.1. Two waste categories stand out with relatively high mean values. These are kitchen waste ($\bar{x}$ = 3.18 kg/hh/wk) and newsprint (1.24 kg/hh/wk). The mean values of the remainder of the components are each less than 1.0 kg/hh/wk with the lower limit marked by non-ferrous metals ($\bar{x}$ = 0.17 kg/hh/wk).

5.3.5 The component categories of household waste differed substantially in terms of the amount of varability which they exhibit. The relative dispersion of the different components can be compared in terms of their coefficients of variation. The waste categories which varied most were textiles, garden waste, and the two miscellaneous categories. Each of these categories had a coefficient of variation in excess of 200% (i.e. the standard deviation in each case was more than twice the mean). The variability can be explained partly in terms of the origins of these types

Table 5.3 Summary of the Characteristics of the Distributions of the Component Categories of Waste

Waste Categories	% of samples in which type of waste found	Absolute Weight			Percentage		
		Mean $\bar{x}$ Kg	Coefficient of Variation CV	Approximate Shape	Mean $\bar{x}$%	Coefficient of Variation CV	Approximate Shape
Kitchen Waste	95%	>2.0	75 - 150%	Skewed Normal	>20	75%	Skewed Normal
Newsprint	85%	2.0 - 1.0	75 - 150%	Skewed Normal	20- 10	75 - 150%	Skewed Normal
Scrap Paper etc. Cardboard Ferrous Metals Glass Plastic Film Dense Plastic	75%	<1.0	75 - 150%	Skewed Normal	<10	75 - 150%	Skewed Normal
Non-Ferrous Metals Fines	60%	<1.0	150 - 225%	Negative Exponential	<10	150 - 225%	Negative Exponential
Textiles Garden Waste Misc. Combustible Misc. Non-Combustible	40%	<1.0	225%	Negative Exponential	<10	225%	Negative Exponential

of waste. Garden waste which consists largely of weeds, tree prunings etc., tends to be generated in batches as the need for weeding or pruning arises, as opposed to on a regular weekly basis. Textiles waste in the form of clothing or household fabrics also tend to be disposed of in a discontinuous fashion. Many types of 'miscellaneous' items are obsolescent durable goods such as small-sized electrical appliances, footwear and childrens toys which are discarded only at the end of the product's life cycle. By contrast the categories with the smallest dispersions were kitchen waste, newsprint and packaging material, all of which tend to be generated on a continuous weekly basis. Kitchen waste was found to have the lowest coefficient of variation (CV = 84.6%). Almost three quarters of all samples of waste contained between 0 kg and 4.0 kg of kitchen waste. This is consistent with the fact that food derived waste is a regular ingredient to all dustbins. Newsprint (CV = 115%) also tends to be disposed of regularly since newspapers became 'obsolete' as soon as a new edition is published.

5.3.6 An additional factor which is likely to affect variability is the basic unit size in which the waste occurs. This is illustrated by the range in dispersions of different types of packaging waste. Plastic film which is made up of small scraps of material has a coefficient of variation of 90%; by contrast dense plastic which is made up of large, discrete items has a coefficient of variation of 148%. The difference in the two dispersions is illustrated in Figures 5.3 and 5.4.

Fig. 5.3 Frequency distribution of plastic film waste (kg/hh/wk)

```
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
    0.0       218     ***************
    0.2       633     *******************************************
    0.4       268     ******************
    0.6        89     ******
    0.8        43     ***
    1.0        11     *
    1.2         5     *
    1.4         5     *
    1.6         3     *
    1.8         0
    2.0         1     *
    2.2         0
    2.4         1     *
```

Fig. 5.4 Frequency distribution of dense plastic waste (kg/hh/wk)

```
EACH * REPRESENTS  20 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
    0.0       867     ********************************************
    0.5       367     *******************
    1.0        26     **
    1.5         7     *
    2.0         5     *
    2.5         1     *
    3.0         2     *
    3.5         0
    4.0         1     *
    4.5         0
    5.0         0
    5.5         0
    6.0         0
    6.5         0
    7.0         1     *
```

5.3.7 The third parameter which distinguishes the individual distributions (in addition to location and dispersion) is the shape of the distribution. In Table 5.3 a coarse distinction has been made between 'skewed normal' and 'negative exponential' type distributions. A normal distribution is expected whenever a measurement is affected by a large number of independent factors, no single one of which predominates. The distributions of the waste components depart from normality in two main respects, firstly through the occurrence of extreme values at the upper ends of the distributions, and secondly through the predominance of zero values. These features are illustrated by the cumulative frequency distributions of kitchen waste and miscellaneous non-combustible waste shown in Figures 5.5 and 5.6 respectively. The extended right hand tail at the upper end of the distribution in Figure 5.5 and the absence of a corresponding tail at the lower end indicate positive skewness. The point of intercept of the distribution with the vertical axis in Figure 5.6 indicates a distribution dominated by zero.

5.3.8 The phenomenon of positive skew can be explained by the occurence of unrepresentatively large quantities of waste, often in an atypical form e.g. a sack of spoiled vegetables in the kitchen waste category, a plastic washing-up bowl in the dense plastic category or aluminium cooking utensils in the non-ferrous category. The negative exponential type distributions exemplified by garden waste, textiles and miscellaneous wastes tend to combine extreme values with high zero values. For example garden waste was found in fewer than half of all waste samples, but some of those samples consisted entirely of garden waste.

Distributions of Individual Waste Components Measured in Percentages

5.3.9 This section describes the distributions of measurements of the component categories of household waste expressed in terms of their percentage of the total weight of waste. There are two reasons for examining waste measurements in percentage terms as well as in terms of absolute weight. Firstly, in certain circumstances, percentage statistics are intrinsically more interesting than measures of absolute weight. For example the suitability of household waste for salvage or for the production of refuse derived fuel is determined by the ratio of potentially useful material to scrap. Secondly there may be grounds for building a household waste model based on percentages. This approach would be justified if the ratio of systematic to random variance in waste arisings were higher when the waste was measured in percentage terms as opposed to in terms of absolute weight.

5.3.10 The distributions of the component categories of household waste expressed in terms of percentages were found to mirror to a large extent the distributions of the same categories expressed in terms of weight. The distribution of percentages of kitchen waste approximates most closely to a normal distribution as shown in Figure 5.7. The same category also has the largest mean ($\bar{x}$ = 32%) and the smallest relative variance (CV = 55%) of all the component categories. Three quarters of all waste samples contained between 20% and 50% of kitchen waste. By contrast, percentages of garden waste, textiles and miscellaneous wastes all exhibited negative exponential type distributions with coefficients of variation in excess of 200%. The extent of skewness in these distributions is illustrated by the fact that although the mean level of garden waste was 6%, three quarters of all households generated less than 5% of this type of waste.

5.3.11 The characteristics of the distributions of different categories of packaging waste fell between the extremes represented by kitchen waste and garden waste. The distributions were skewed normal in shape with mean values between 2.4% (dense plastic) and 9.4% (glass) and coefficients of variation between 75% and 150%. Fewer than a quarter of waste samples contained in excess of 10% of any individual type of packaging waste (i.e. either paper, cardboard, ferrous metal, glass or plastic). Conversely, no type of packaging waste was absent altogether from more than a quarter of the waste samples.

5.3.12 Sample measurements of newsprint were distributed in a skewed normal pattern, with a mean of 12.5% and a coefficient of variation of 98% (i.e. the standard deviation of the distribution was almost exactly equal to the mean). Almost

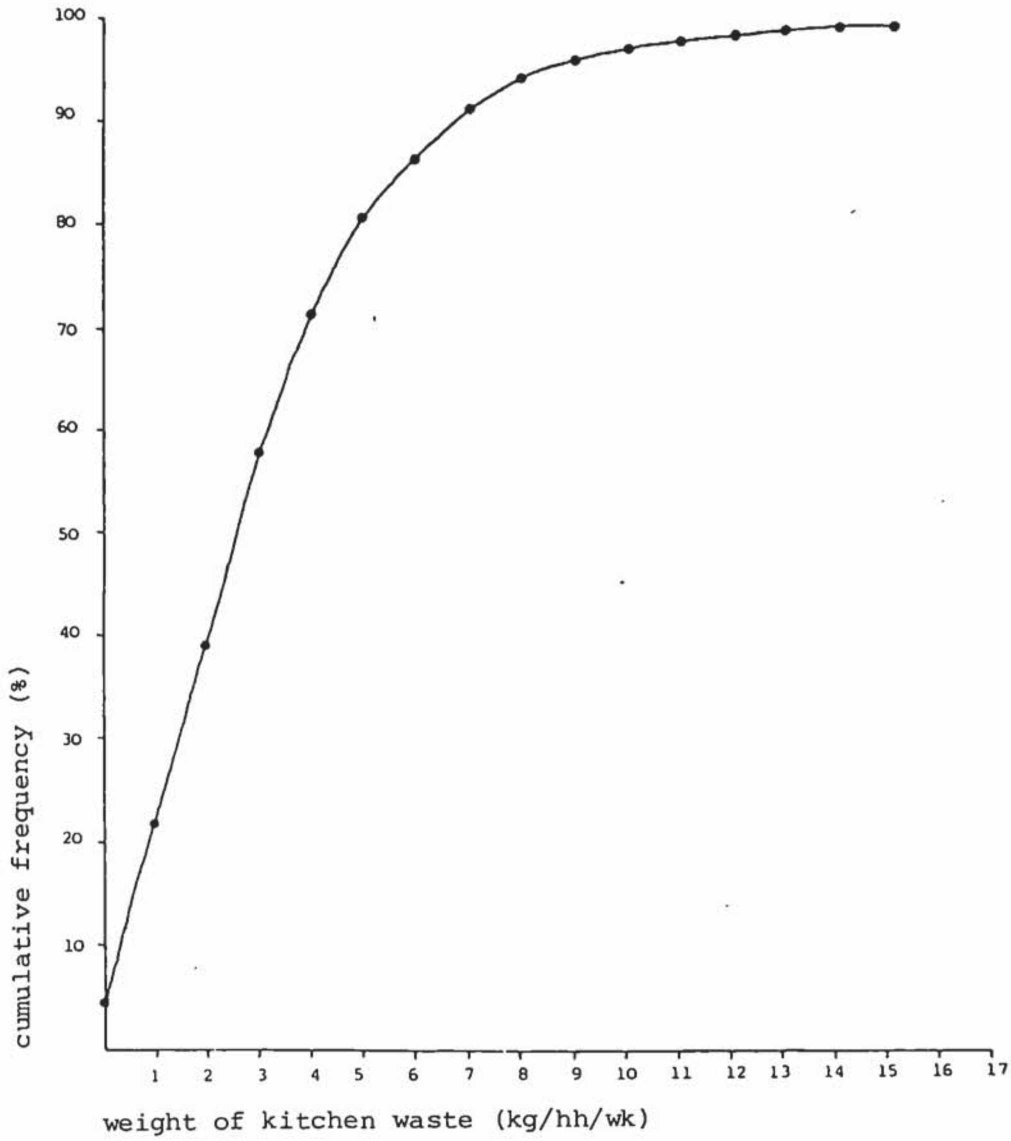

Fig. 5.5 Cumulative frequency distribution of kitchen waste

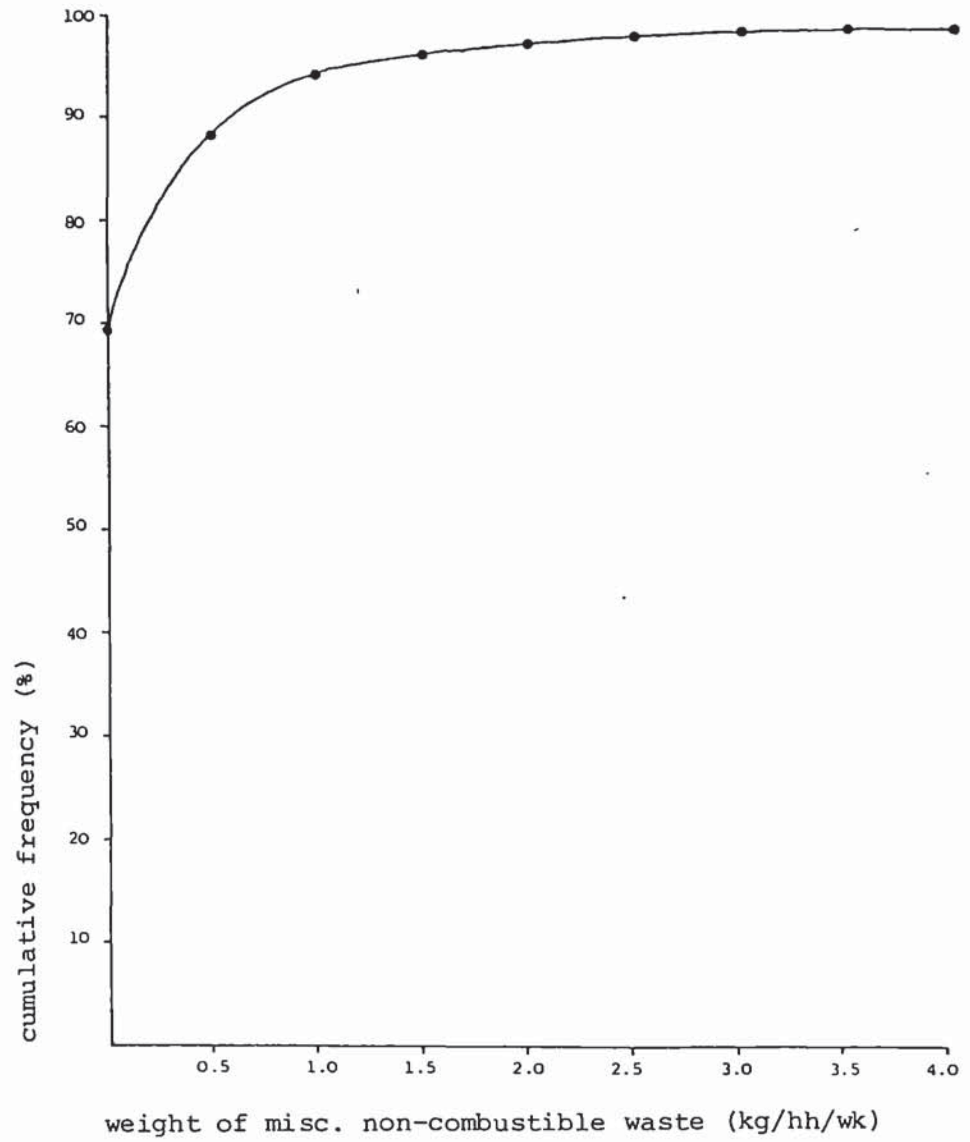

Fig. 5.6 Cumulative frequency distribution of miscellaneous non-combustible waste

Fig. 5.7 Frequency distribution of kitchen waste (% weight)

```
EACH * REPRESENTS  10 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
     0       84    *********
    10      130    *************
    20      236    ************************
    30      279    ****************************
    40      255    **************************
    50      166    *****************
    60       76    ********
    70       30    ***
    80        7    *
    90        3    *
```

three quarters of all households generated between 0 and 15% of newsprint.

5.3.13 The distributions of percentage levels of fines and non-ferrous metals were characterised by high concentrations of measurements at the low end of the scale. More than 90% of waste sample contained less than 5% of non-ferrous metals and more than 90% of samples contained less than 5% of fines. This feature, combined with a small number of extreme values at the upper ends of the distributions accounts for the marked positive skew in each case.

5.3.14 A comparison of the distributions of the same waste categories expressed in terms of absolute weight and as percentages indicates that there is slightly less variability within the distributions of 'percentage' values than within the corresponding distributions of absolute weights. This is to be expected partly as a result of the 'self-correcting effect' which results from dividing the weights of each of the component categories by the total weight of waste in which the categories are represented. The largest difference in variability between the 'absolute' and 'percentage' distributions corresponds to the fines category for which the coefficients of variation are 225% and 156% respectively. This is consistent with the fact that nearly all types of waste contribute to some extent to the fines category (e.g. in the form of scraps of paper, cigarette stubs, organic material) and therefore the quantity of fines is linked to the quantity of total waste. In general, however, the evidence of the distributions is that the component categories of waste are relatively independent of one another and that the system of waste categorisation adopted is successful in discriminating between waste from independent origins.

Summary

5.3.15 This section has described the similarities and contrasts which exist between the distributions of component categories of household waste (expressed in terms of both weights and percentages) and has demonstrated how the compositions of the categories affects the characteristics of the distributions. The most pronounced common feature observed in relation to all of the distributions was the large dispersions. Only in a small number of cases was the standard deviation of the distribution found to be less than its mean (i.e. was the coefficient of variation is less than 100%). In some cases the standard deviation was found to exceed the mean by up to three and half times. The extent of variation in waste arisings between households is important in the context of waste modelling. It militates against the use of a simple 'average waste per household' approach to the estimation of waste arisings because of the high intrinsic error involved. However, this is not in itself sufficient evidence that a model based on measurable household characteristics could offer a substantial improvement in accuracy. It must first be established that a significant proportion of the variation in waste arisings is systematic as opposed to random. The relative proportions of systematic and random variance are the subject of section 5.5 in this chapter. The following section examines the extent to which the sample distributions conform to theoretical distributions, and the implications for subsequent data analysis.

5.4 Goodness of Fit of Sample Distributions to Theoretical Distributions

5.4.1 The rationale for establishing how closely the sample distributions approximate to theoretical distributions is as follows: if a sample distributions can be shown to derive from a population with the known features of a theoretical distribution, then this information can be used in the construction of regions for the acceptance or rejection of hypotheses. Specifically, the information can be used to judge whether two different sample groups belong to populations with the same mean, or whether they are drawn from populations with different means.

5.4.2 The sample distributions were tested for 'goodness of fit' against three different theoretical distributions: the normal distribution, the log normal distribution and the Poisson distribution. The equality between the sample distributions and the theoretical distributions were tested using the Kolmorogov-Smirnov test, available as a computer routine on the Aston University HARRIS computer. The test is sensitive to any type of difference between two distributions including differences in the medians, dispersions and skewness (Siegal 1956). In addition, the goodness of fit of the distribution of measurements of total waste was tested using the conventional chi-squared test.

5.4.3 Both types of test found the sample distributions to be significantly different to the theoretical distributions. However, it was noted that because of the large sample sizes involved the tests were very conservative (i.e. the maximum permitted discrepancy between the sample and theoretical distributions in order to establish equality between the two was very small). Two sample distributions ('total waste' and 'kitchen waste') were therefore plotted on normal and log normal probability scales in order to determine the exact size and nature of the discrepancies in each case. The plots are shown in Figures 5.8 to 5.11. The positive skew of the two distributions is reflected in the convexity (with respect to the axis) of the plots on the normal scale. The process of log transformation has the effect of normalising the upper halves of the two distributions whilst exaggerating the departure from normality in the lower halves; hence the change in the shape of the curves from convex to concave with no improvement in goodness of fit.

5.4.4 On the basis of these findings it is possible that the samples of household waste derive from a 'split population' and that patterns of waste generation are different among the 'low level' and 'high level' waste producers. This explanation would account for the apparently 'normal' shape of the lower halves of the plotted distributions and the

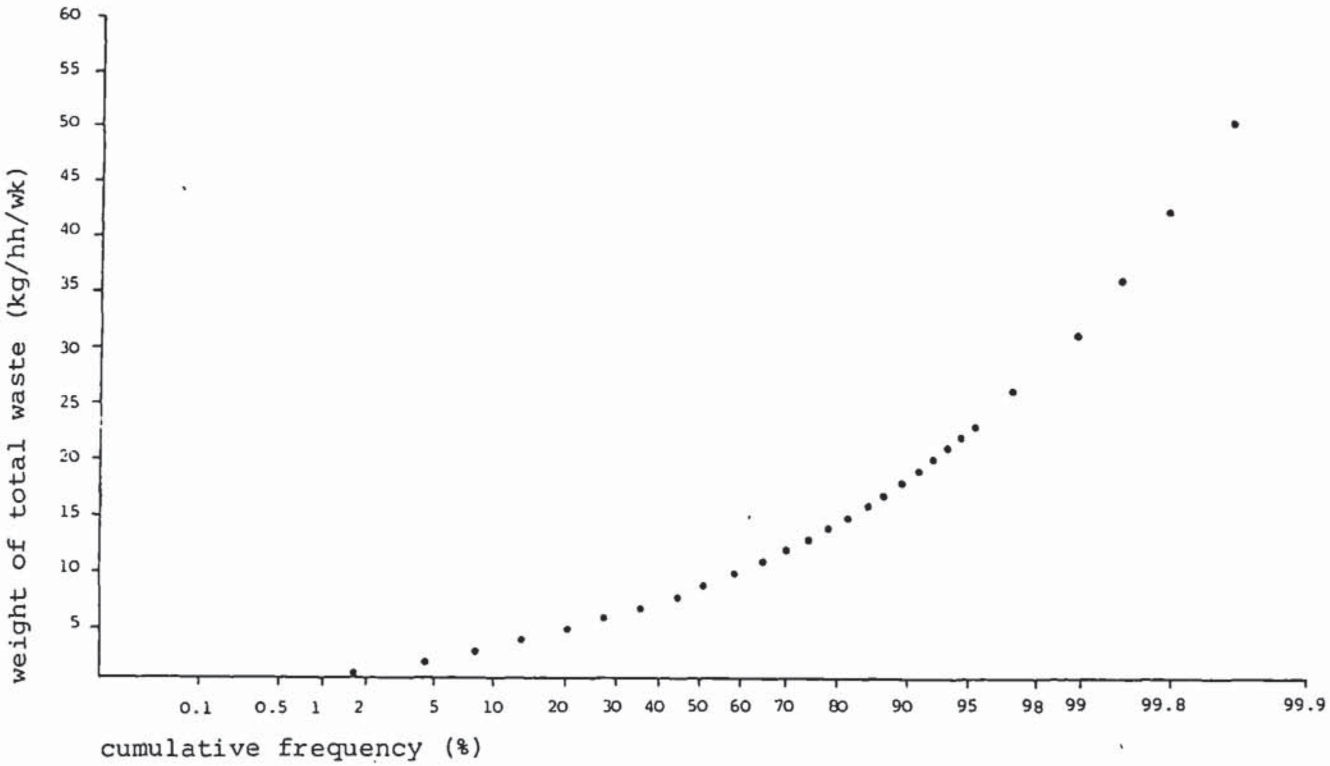

Fig. 5.8 Plot of cumulative frequency of total waste arisings on normal probability scale

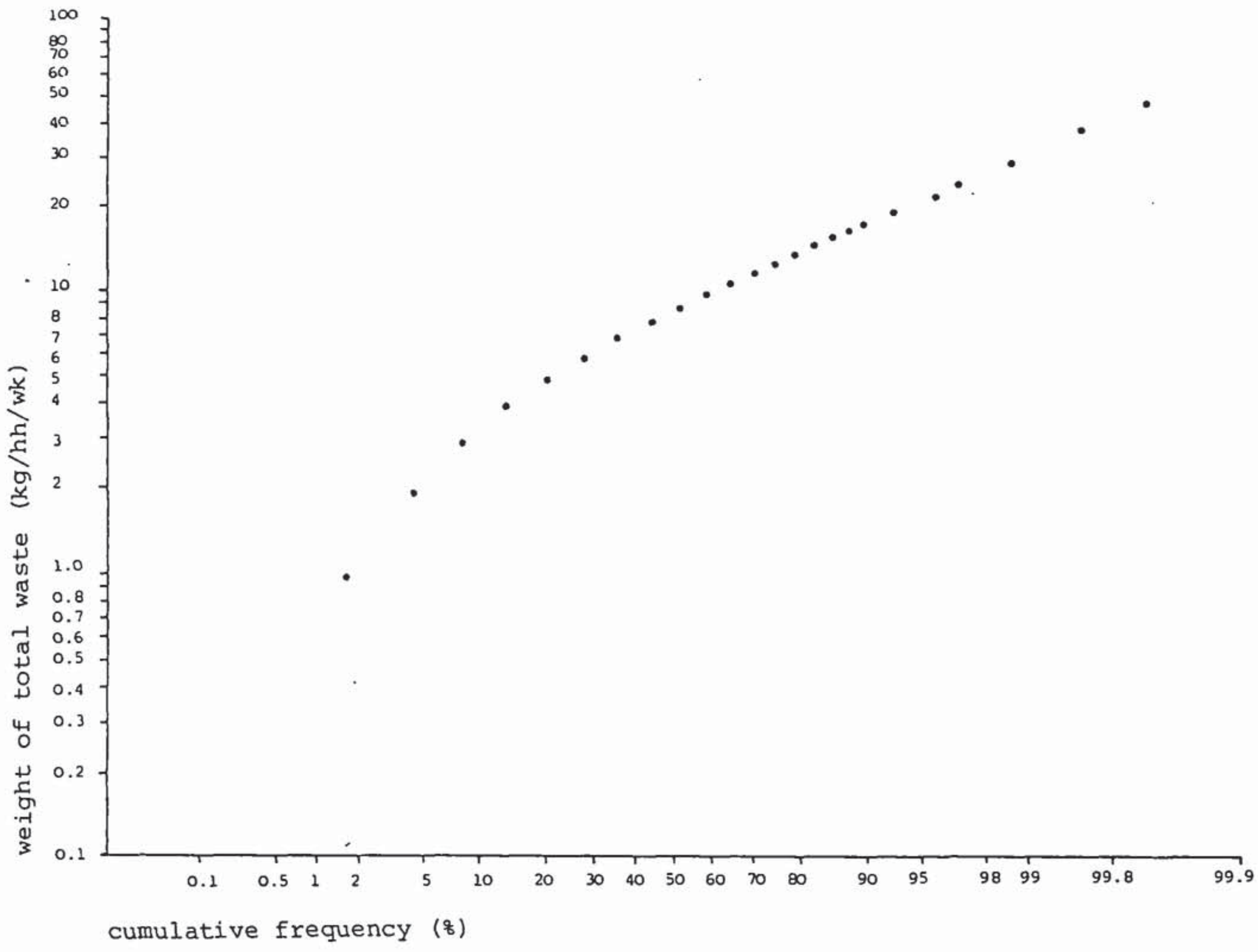

Fig. 5.9 <u>Plot of cumulative frequency of total waste arisings on log normal probability scale</u>

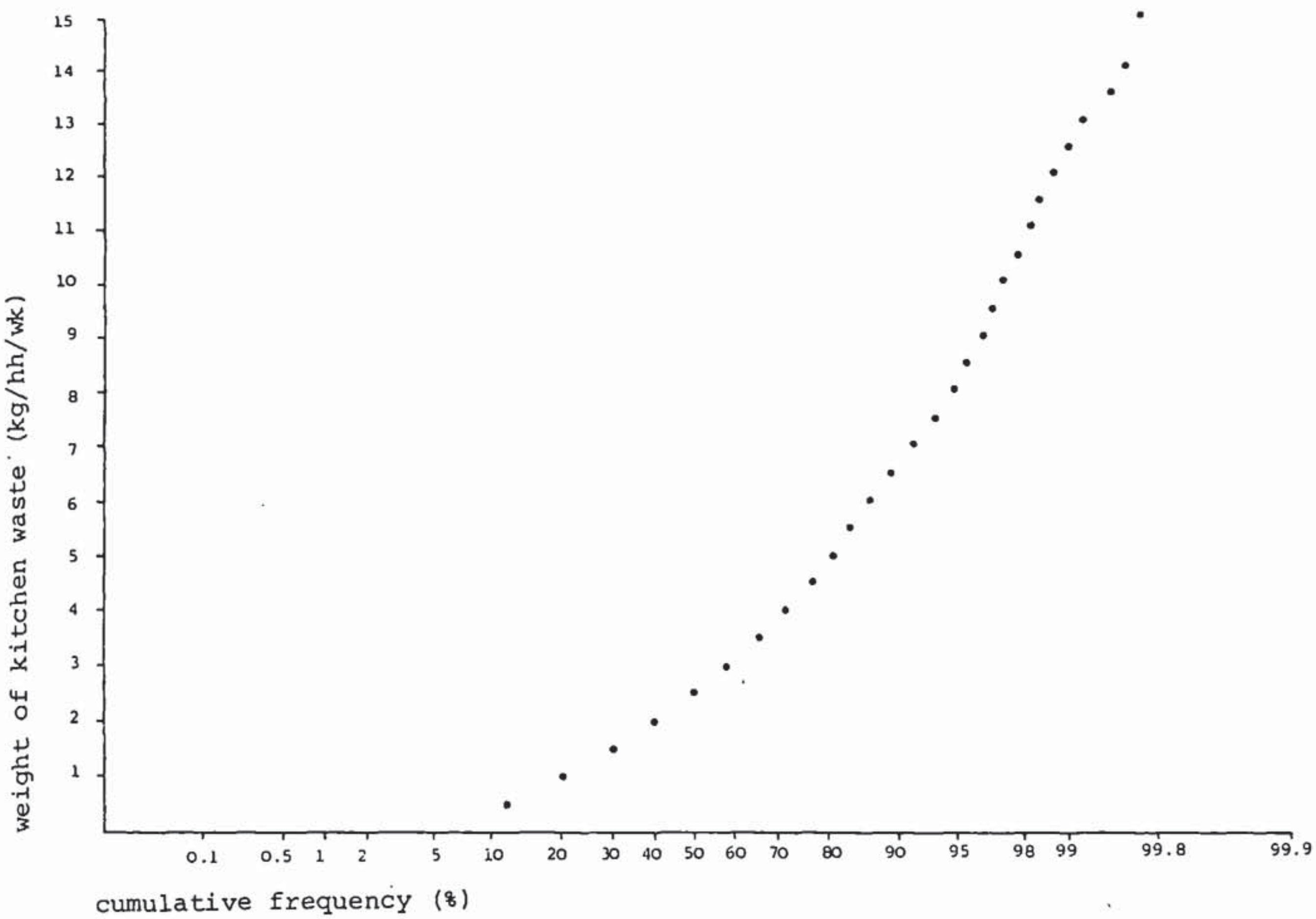

Fig. 5.10 Plot of cumulative frequency of kitchen waste on normal probability scale

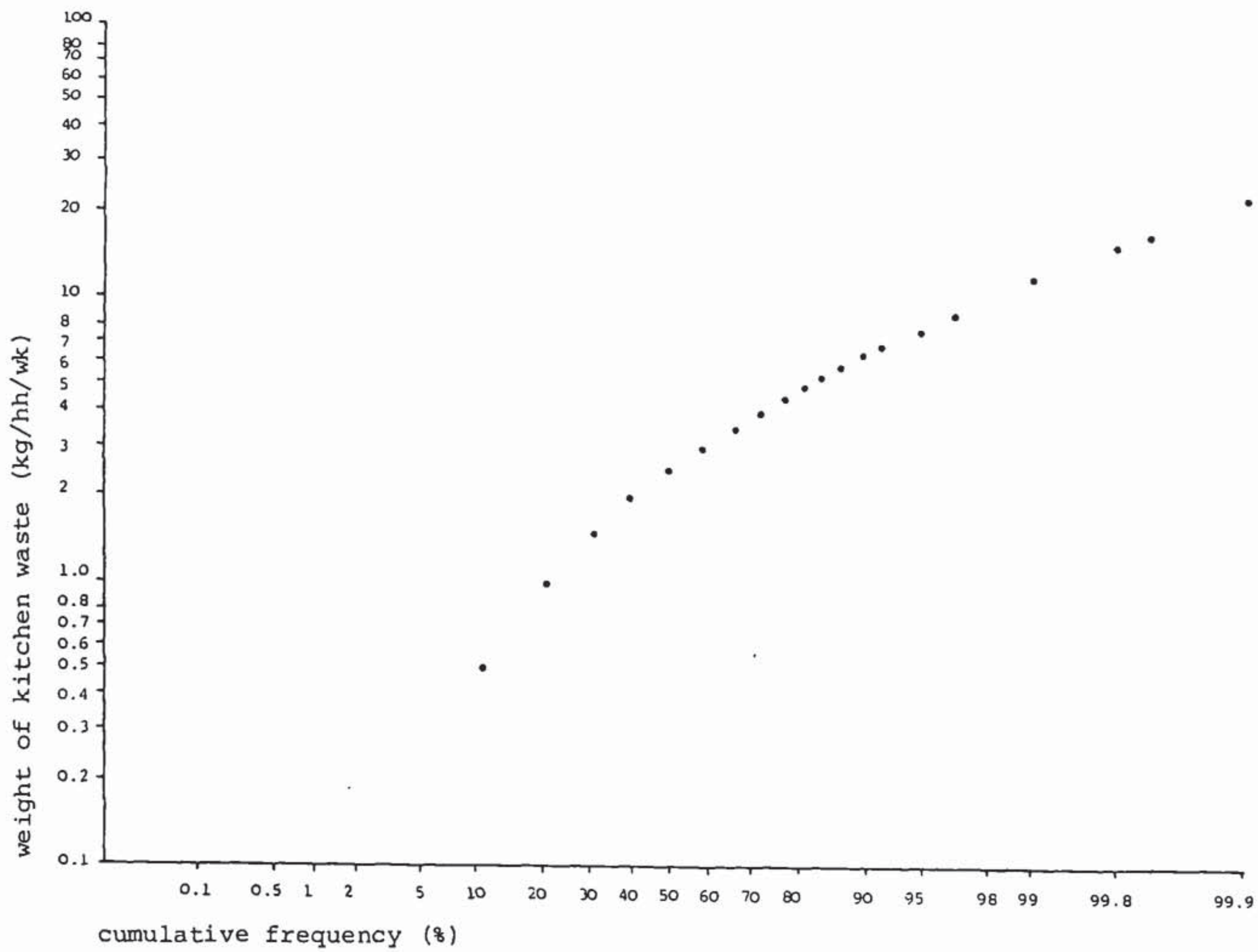

Fig. 5.11 Plot of cumulative frequency of kitchen waste on log normal probability scale

log normal shapes of the upper halves. In principle, it would be possible to divide the population of households into two groups and to base inferential tests on the appropriate type of theoretical distribution for each group. However, this approach creates difficulties in the use of computer routines such as multiple regression which use tests based on the normal distribution as criteria for the entry of variables.

5.4.5 In the circumstances, given the time and resources available for this research, hypotheses concerning the differences between sample groups were tested using statistical methods based on the assumption of normality in the parent populations. Because the distributions of waste measurements were not strictly normal the statistical methods are less powerful, in the sense that the risk of falsely accepting or rejecting a hypothesis is increased. It is not possible to determine exactly the extent or the implications of this increase in risk, although it is recognised (Robson 1973) that the outcomes of many tests based on the normal distribution are generally resistant to departures from normality.

5.5 Apportionment of Variance

5.5.1 This section presents and interprets the findings of the subsidiary surveys carried out in order to investigate the two random elements of variance in waste arisings, namely the variance in the waste arisings of a single household from week-to-week, and the error involved in the measurement of waste arisings. The purpose of investigating random variance has been discussed in detail in section 4.2.6. To recap, the size of random variance in relation to systematic variance is important in two respects:

(1) It indicates the accuracy and representativeness of using a single week's waste to represent the 'true' intrinsic average waste arisings of an individual household.

(2) It represents the proportion of total variance in waste arisings which cannot be explained in terms of substantive differences between households, and therefore delimits the potential accuracy of a waste arisings model based on household characteristics.

The magnitude of each element of random variance is given below. On the basis of these findings, the magnitude of systematic variance is derived by the method of root mean squared (r.m.s.) addition of variances. The question of 'normality' and 'independence' in the two random variance elements is also addressed.

Week-to-Week Variance

5.5.2 Week-to-week variance was determined on the basis of measured changes in waste arisings over three weeks among 73 individual households. Frequency plots of the changes in total waste arisings between weeks 1 and 2 and between weeks 2 and 3 (Figures 5.12 and 5.13 respectively) show the distributions to be statistically normal. Week to week variation in total waste arisings was also plotted against the absolute weight of total waste generated by each individual household (Figure 5.14). There was no apparent relationship between the two, and weekly variation in waste was therefore assumed to be independent of the level of waste arisings.

5.5.3 An estimate of week to week variance in waste arisings was obtained on the basis of the relationship shown below:

$$\sigma^2_{wk} = \frac{\sigma^2_{dk}}{2n}$$

where σ^2 wk is the week to week variance in waste type k

and σ^2 dk is the variance of the pooled distribution of d' (waste level in week 1 minus waste level in week 2) and d" (waste level in week 2 minus waste level in week 3)

The values of week to week variance for total waste and each of the component categories is given in Table 5.4.

5.5.4 Also shown in Table 5.4 are the standard deviations of the between-week differences in waste levels expressed both in absolute terms and as percentages of mean waste levels. This information is useful since it makes it possible to calculate the sample size necessary to estimate the mean level of waste from households with the same intrinsic

Fig. 5.12 Distribution of the difference in total waste arisings from individual households between survey week 1 and survey week 2 (kg/hh/wk).

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	25	*************************
2	30	******************************
4	5	*****
6	9	*********
8	3	***
10	0	
12	0	
14	0	
16	0	
18	0	
20	1	*

Fig. 5.13 Distribution of the difference in total waste arisings from individual households between survey week 2 and survey week 3 (kg/hh/wk).

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	9	*********
1	23	***********************
2	9	*********
3	7	*******
4	3	***
5	7	*******
6	6	******
7	4	****
8	0	
9	1	*
10	1	*
11	1	*
12	1	*
13	1	*

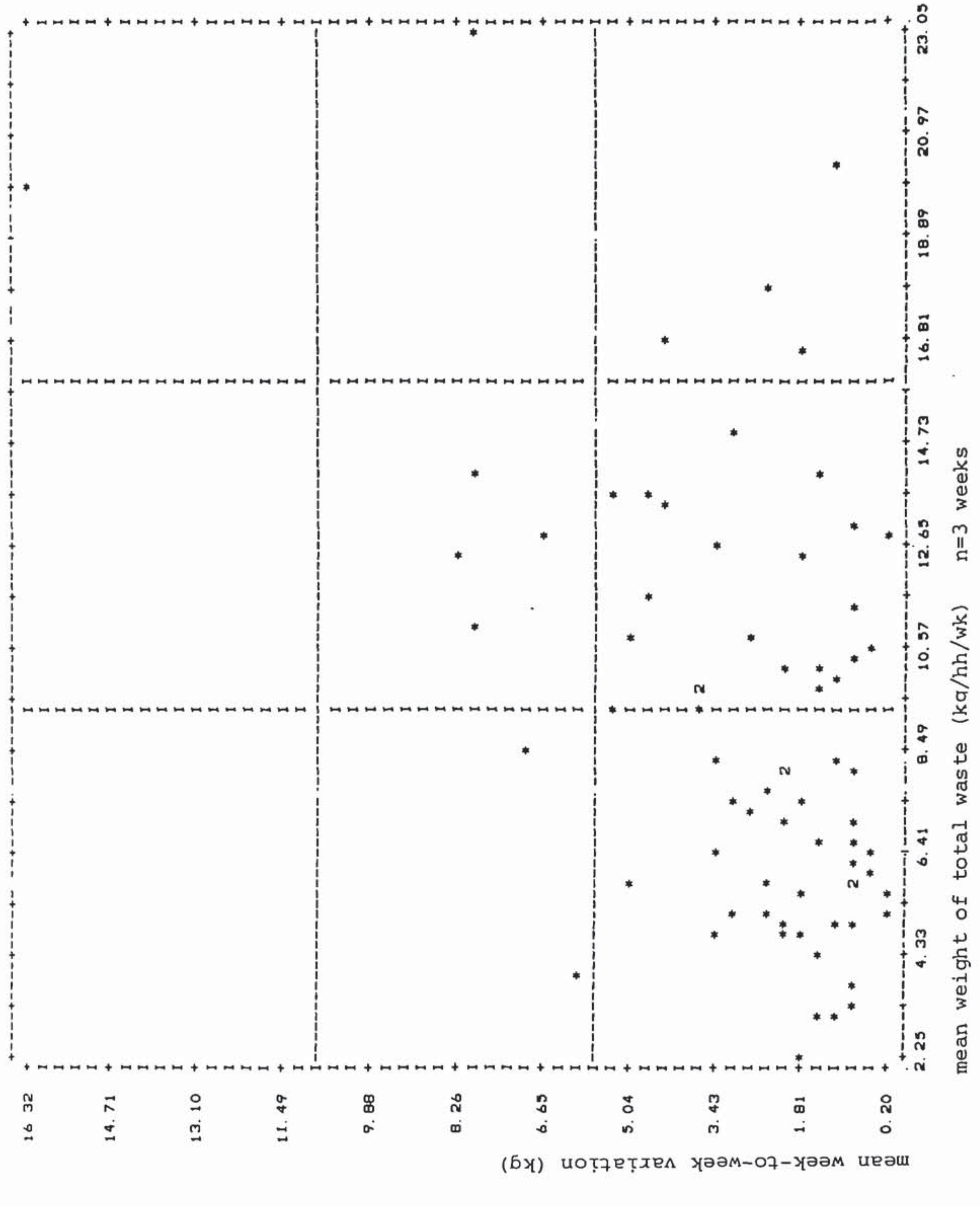

Fig. 5.14 Scattergram of week-to-week variation in total waste arisings against mean weekly weight of total waste arisings

average, within a given margin of error. For example, Table 5.4 shows that measured total waste in any one week is within $\pm$ 26% of the true mean level over a period of weeks. To achieve an error of estimate of $\pm$ 5% a sample of 26 households with the same intrinsic average is required. Larger sample sizes are needed to achieve a 5% margin of error for individual categories of waste since the week to week variance is greater for the individual components than for the total.

Measurement Error

5.5.5 Estimates of measurement error involved in the handsorting and weighing of waste were obtained by the repeat sorting of ten dustbins by four separate teams of operators to give ten independent estimates of error for each type of waste. No significant differences were found within each group of error estimates and single, more robust estimates of measurement error were therefore derived by pooling. The pooled estimates of error are given in Table 5.5. There was no quantifiable error involved in the sorting of paper, card or dense plastic, since these components were easily identified and separated. It was not possible to carry out independent measurements of the fines category since repeated sorting of the same dustbin led to the progressive breakdown of friable waste materials (particularly organics) and an associated increase in the weight of the fines category. It is likely that error did occur in the measurement of fines and also in the measurement of garden

Table 5.4 Weekly Variation in Waste Arisings and Implications for Choice of Sample Size

Waste Categories	Mean Weight of Waste Arsisings $\bar{x}$ (kg/hh/wk)	Week-to-Week Variance σ_j^2	Standard deviation of weekly variation as a percentage of mean weight of waste $\frac{\sigma_j \cdot 100\%}{\bar{x}}$	Necessary sample size to achieve error of estimate of 5% $n = \left(\frac{\sigma_j \cdot 100\%}{\bar{x} \cdot 5}\right)^2$ (number of households)
TOTAL	10.11	6.76	25.7	26
Kitchen Waste	3.18	1.94	43.8	77
Garden Waste	0.65	1.52	192.0	1475
Scrap Paper etc	0.70	0.09	42.8	73
Newsprint	1.24	0.65	65.5	172
Card	0.54	0.11	60.9	148
Ferrous	0.60	0.09	49.1	96
Non-Ferrous	0.08	0.01	132.9	706
Textiles	0.31	0.34	187.4	1405
Glass	0.97	0.46	69.5	193
Plastic Film	0.27	0.02	55.4	123
Dense Plastic	0.23	0.01	51.9	108
Misc. Combustible	0.53	1.37	222.0	1971
Misc. Non-Combustible	0.23	0.34	253.0	2560
Fines	0.45	0.20	99.8	398

Table 5.5 Random Elements of Variance in Waste Arisings Expressed in Absolute and Percentage Terms

Waste Categories	Total Observed Variance	Measurement Error		Week-to-Week Variance		Total Random Variance	
	σ_p^2	σ_k^2	$\frac{\sigma_k^2 \cdot 100\%}{\sigma_p^2}$	σ_j^2	$\frac{\sigma_j^2 \cdot 100\%}{\sigma_p^2}$	$\sigma_j^2 + \sigma_k^2$	$\frac{(\sigma_j^2 + \sigma_k^2) \cdot 100\%}{\sigma_p^2}$
TOTAL	41.99	NA	NA	6.76	16.1	6.76	16.1
Kitchen Waste	7.25	0.03	0.4	1.94	26.7	1.97	27.1
Garden Waste	3.37	0.03*	0.9	1.52	45.8	1.55	46.7
Scrap Paper etc	0.55	0	-	0.09	16.1	0.009	16.1
Newsprint	2.02	0.02	1.0	0.65	32.4	0.67	33.4
Cardboard	0.37	0	-	0.11	29.2	0.11	29.2
Ferrous	0.38	0.03	7.9	0.09	23.4	0.12	31.3
Non-Ferrous	0.03	0.03	100	0.01	34.5	0.04	134.5
Textiles	0.96	0.03	3.1	0.34	34.9	0.37	38.0
Glass	1.69	0.01	0.6	0.46	27.1	0.47	27.7
Plastic Film	0.06	0.01	16.7	0.02	40.0	0.03	56.7
Dense Plastic	0.12	0	-	0.01	12.1	0.01	12.1
Misc. Combustible	1.67	0.01	0.6	1.37	81.8	1.38	82.4
Misc. Non-Combustible	0.67	0.01	1.5	0.34	50.5	0.35	52.0
Fines	1.02	0.03*	2.9	0.20	19.5	0.23	22.4

waste which was absent from all ten bins used in the exercise. Estimates of error were therefore allocated to these two categories (the estimates represent the maximum levels of measurement error recorded among the other waste categories, on the principle that it was preferable to be over cautious than to underestimate the extent of error).

5.5.6 Table 5.5 indicates that the waste category with the highest recorded level of measurement error as a proportion of the mean was non-ferrous metal. This result can be explained partly by the fact that non-ferrous materials frequently occurred in a form that was difficult to separate and weigh (e.g. as aluminium collars on bottles or as paper-backed foil). Figure 5.15 shows a plot of the sorting error associated with kitchen waste against the corresponding mean levels of kitchen waste for each of the ten sample bins. No relationship is evident from the plot and sorting error was therefore assumed to be independent of the absolute weight of waste (kitchen waste provided a good basis for this generalised conclusion since, because of its unpleasant and intractable nature, it was the most likely of all components to be associated by quantity with errors of measurement).

Estimation of Systematic Variance

5.5.7 Having established the magnitude of week to week variation in waste arisings and the magnitude of measurement error,

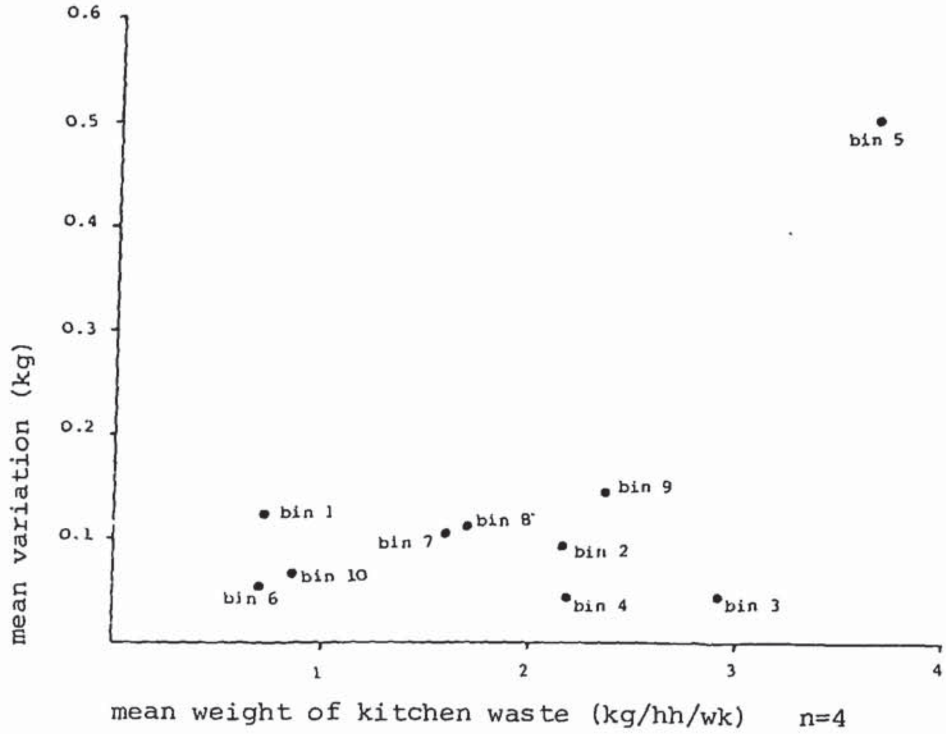

Fig. 5.15 <u>Scattergram of handsorting error associated with kitchen waste against mean weight of kitchen waste</u>

a series of estimates of the systematic variance in waste arisings was derived. Table 5.5 shows weekly variance and measurement error in terms of both absolute weight and as proportions of the total observed variance in waste arisings between households. By subtracting 'random variance' from 'total variance' estimates of the variance due to systematic and substantive differences in waste arisings between households were obtained. The way in which the different elements of variance combine can be expressed as follows:

$$\sigma_p^2 = \sigma_i^2 + \sigma_j^2 + \sigma_k^2$$

where σ_p^2 = total observed variance

and σ_i^2 = systematic variance

and σ_j^2 = week to week variance

and σ_k^2 = measurement error

The above relationship is based on the assumptions of normality and independence in the variance elements, which were satisfactorily established.

5.5.8 Table 5.5 (column 7) indicates that approximately 16% of the observed variation between households in total waste arisings is the result of week to week variance and measurement error. The vital corollary is that up to 84% of the variance in total waste arisings can potentially be explained in terms of the substantive differences that exist between households. The proportion of random variance associated with nearly all of the component categories of waste lie between 20% and 60% and, by implication, the proportion of systematic variance is therefore between 40% and 80%. The table contains one anomalous result, that for non-ferrous metal. The size of random variance is greater than total variance in this case and must be attributed to the exceptionally high estimation of measurement error obtained.

5.5.9 The next stage in the research involved determining what proportion of the systematic element of variance in waste arisings could be explained in practice on the basis of the measurable characteristics of households. This process is described in Chapter 6.

5.6 Conclusions

5.6.1 In summary, the key findings reported in this chapter are:

(1) The close correspondence between the results of the household waste survey carried out as part of this research and the results of other UK wastes surveys.

(2) The complexity of the distributions of waste categories and the similarities and contrasts between those distributions.

(3) The substantial size of the systematic element of the variance in waste arisings in relation to the random element of variance.

5.6.2 These findings have a number of implications. Firstly, the comparability of the survey results with the results of other UK surveys confirms that the data upon which the model-building exercise in this research has been based are representative and generalisable. Secondly, the study of the distributions of waste measurements has generated new information about the patterns of waste arisings within the population and about the relationships between the characteristics of the distributions and the composition of the component categories of household waste. Thirdly, the most significant conclusion of the chapter from the perspective of waste modelling concerns the relative proportions of random and systematic variance in waste arisings. This information is of considerable value in the future design of waste surveys and in the interpretation of the survey findings. The results indicate that it is possible to substantially improve the current understanding of the process of household waste generation, and they highlight the potential strength and usefulness of a waste arisings model based on household characteristics.

CHAPTER SIX

DEVELOPMENT OF A HOUSEHOLD-BASED BEHAVIOURAL METHOD FOR PREDICTING WASTE GENERATION

6.1 Introduction and Aims

6.1.1 This chapter describes how the research responded to the second and third objectives, namely to distinguish between waste arisings from households of different types, and to explain and predict those differences through a household-based behavioural model. The chapter describes the statistical methods used to test the hypothetical relationships between household characteristics and waste arisings, and also gives a qualitative interpretation to those relationships in terms of household behavioural characteristics.

6.1.2 The discussion is divided into two stages reflecting the twin research objectives that are addressed. The first stage investigates the statistical associations between waste arisings and each of the individual household characteristics that were measured through the questionnaire survey described in Chapter 4. Taking each household variable in turn, households are combined into groups corresponding to the categories by which each of the variables was scaled and recorded in the questionnaire. The statistical distributions of measurements of household waste within each group of households are studied and compared using a statistical technique called one way analysis of variance.

The analytical procedure for this is described in section 6.2 and the results of the analysis are given in section 6.3.

6.1.3 In the second stage the effects of household characteristics on waste arisings are considered jointly as opposed to individually. The purpose is to take account of the inter-relationships that exist between household characteristics and to approach as closely as possible to the estimation of causal relationships (i.e. relationships that imply 'consequence' as well as 'coincidence') between household descriptors and waste arisings. The investigation of the joint effects of household characteristics provides the basis for the development of two types of statistical model which can be used to explain and predict waste arisings at the 'individual household' level. A full account of the underlying principles, the statistical methodology and the results of model development is given in section 6.4 and 6.6. An evaluation of the performance of the two models, against the performance of existing methods of waste estimation in current use is presented in section 6.7.

6.2 Investigation of the Association Between Waste Arisings and Individual Household Characteristics

6.2.1 This section describes the statistical method used to investigate the relationships between individual household characteristics and waste arisings. The method was based on the application of a statistical technique called 'one way analysis of variance' to the data set containing information on 1277 households. The technique involved a number of steps:

(1) Data on household waste arising were divided into groups according to each of the household characteristics (e.g. to investigate the association between waste arisings and tenure, households were combined into four groups: owner occupied, housing association, council rented and 'other rented').

(2) Two types of variation were measured: firstly the amount of variation in waste arisings within each household group, and secondly the amount of variation between the different household groups.

(3) The ratios of variance between groups to variance within groups (termed 'F ratios') were calculated and then compared with 'critical values' obtained from a theoretical 'F' distribution. On the basis of the results the sample groups were judged to have derived either from populations with the same mean (if F lay below the critical value) or from populations with different means (if F exceeded it). Hence, if the F-ratio exceeded the critical value, it was concluded that a statistically significant association existed between the variable according to which the households had been grouped, and household waste. The method was thus one for testing

the hypothetical relationships between household characteristics and waste arisings.

6.2.2 Steps (1) and (2) in the procedure described above were carried out using a computerised 'package' available on the University of Aston HARRIS computer. The results are shown in Table 6.1. Categories of waste are set out on the vertical axis of the table and household characteristics are shown along the horizontal axis. Each 'cell' contains a value representing the calculated ratio of between-to-within group variance (denoted by 'Fc'). In some cases a corrected value of F ('Fr') is also given. The purpose of the correction is explained in paragraph 6.2.4.

6.2.3 Where Fc exceeds unity, there is evidence of an association between waste arisings and the household characteristic on which the groupings are based. The critical F values are given at the top of each column in Table 6.1 and represent the upper limits of the regions of acceptance of the 'null hypothesis' that no relationship exists between the particular category of waste and the household characteristics being tested. Hence the critical F values also represent the lower limits of the regions of acceptance of the alternative hypothesis that a relationship does exist. Two critical values of F are given in each case, one representing a 5% chance of falsely rejecting the null hypothesis ($F_{0.05}$) and the other representing a 1% chance of falsely rejecting the null hypothesis ($F_{0.01}$).

Table 6.1 Results of Analysis of Variance on Data from the Household Waste Survey

Household Characteristics / Waste Categories	Smoke Control Zone		Property Type		Tenure		Occupation of Household Head		Type of Domestic Heating		Sink Disposal Unit		Property Size (Number of Bedrooms)		Pet Ownership		Freezer Ownership		Milk Delivered	
Critical Values of F $F_{0.05}$	3.84		2.37		2.60		2.01		3.84		3.84		2.21		3.84		3.84		3.84	
$F_{0.01}$	6.63		3.32		3.78		2.64		6.63		6.63		3.02		6.63		6.63		6.63	
F Calculated	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr
Total Waste	8.60		14.72		10.43		10.36		4.47		0.44		19.68		18.84		54.55		18.47	
Kitchen Waste	1.25		5.89		3.98		8.42		0.36		0.06		12.06		6.29		33.76		17.32	
Garden Waste	1.40		5.33		5.31		1.40	1.64	0.15		0.08		1.95	2.54	0.21		1.26		4.87	
Scrap Paper etc	2.64	3.19	8.70		4.91		6.94		0.18		2.35		9.42		8.75		23.43		8.68	
Newsprint	5.31		5.84		4.40		2.42		0.48		0.84		4.58		4.37		15.03		7.46	
Cardboard	4.68		8.12		1.77		8.73		0.00		2.28		10.16		5.64		38.12		8.03	
Ferrous	3.62	5.37	3.62		1.86	2.43	4.38		0.00		0.05		6.70		42.43		13.54		13.41	
Non-Ferrous	0.14		2.31		2.41		3.15		0.26		0.03		2.34		0.90		4.97		0.92	
Textiles	2.02		1.20		0.38		2.05		3.38	4.74	0.13		1.36		3.37	4.73	7.66		1.79	
Glass	7.11		8.13		6.78		8.59		0.88		0.58		13.38		4.35		11.39		0.23	
Plastic Film	7.50		4.34		7.16		9.28		0.22		0.50		10.78		6.04		23.48		6.59	
Dense Plastic	0.09		1.22		2.74		2.90		0.13		2.85		2.29		2.57	2.90	14.81		1.66	
Misc. Combustible	1.46		3.69		2.87		1.52	2.09	0.27		0.02		0.60		3.25	5.70	0.84		1.82	2.72
Misc. Non-Combustible	0.22		1.41	1.70	1.48		0.76		0.17		0.09		1.68		0.88		2.67	3.86	0.72	
Fines	1.99		1.17		0.75		1.77		55.06		1.23		0.48		5.27		1.04		0.45	

Household Characteristics / Waste Categories	Mode of Newspaper Purchase		Weekly Magazine		Car Ownership		Frequency of Shopping Trips for Food		Age of Domestic Adult		Employment Status of Second Adult		Family Life Cycle		Number of Males		Number of Females		Total Household Size	
Critical Values of F $F_{0.05}$	3.00		3.84		2.60		2.37		2.37		3.00		2.10		2.10		2.37		2.10	
$F_{0.01}$	4.61		6.63		3.78		3.32		3.32		4.61		2.80		2.80		3.32		2.80	
F Calculated	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr	Fc	Fr
Total Waste	2.00	2.26	1.88		22.17		1.45		11.89		2.89	3.37	37.57		27.18		46.06		52.41	
Kitchen Waste	1.54		1.06		13.47		2.51		10.55		3.94		25.66		23.66		34.37		39.53	
Garden Waste	1.70		3.35	4.79	0.93		0.46		8.35		1.03		3.19		1.30		3.68		1.04	
Scrap Paper etc	1.00		1.96		13.89		1.00		7.67		1.20		21.75		14.78		31.16		26.05	
Newsprint	6.88		0.88		3.70		1.03		1.84	2.43	1.96		3.90		2.55		8.08		6.61	
Cardboard	0.95		5.43		11.60		2.23	3.00	10.80		3.55		23.72		20.45		26.19		30.31	
Ferrous	2.49	3.49	0.19		7.86		2.99		5.28		1.96		17.28		12.79		13.10		15.59	
Non-Ferrous	0.14		0.89		1.51		0.48		2.34		0.09		4.78		4.55		2.69		4.32	
Textiles	4.03		0.17		3.90		0.72		1.20		0.70		4.46		4.73		2.85		5.87	
Glass	1.49		0.03		12.64		1.68	2.05	4.74		1.34		11.35		8.42		9.09		10.42	
Plastic Film	4.50		1.22		13.86		3.44		13.62		1.41		28.92		20.82		24.15		30.56	
Dense Plastic	0.75		1.06		6.42		3.82		3.82		1.65		7.60		5.70		9.04		9.65	
Misc. Combustible	2.21	3.54	1.94		1.59	2.24	1.22		1.69		0.31		5.17		3.73		9.52		30.53	
Misc. Non-Combustible	0.14		0.86		0.74		0.51		1.01		0.18		2.22		1.10		1.91	2.57	1.60	2.04
Fines	0.36		1.73		0.38		0.85		1.82				6.43		1.20		1.87	2.06	2.36	

6.2.4 One additional factor was taken into account in the analysis of variance procedure: the effect of random error. In order to make the F test technically valid, certain of the calculated variance ratios were corrected to allow for the distortion of the 'true' variance ratio resulting from the combined effects of week-to-week variance in waste arisings (σ^2_j) and measurement error (σ^2_k). A constant, equal to ($\sigma^2_j + \sigma^2_k$) and specific to each waste category, was subtracted from measures of between group variance and measures of within group variance; this was done in each case where the correction made the difference between a 'significant' or a 'non-significant' result. The net effect of the correction procedure was therefore to bring more of the variance ratios into the 'region of acceptance' of the alternative hypothesis delimited by the critical F values.

6.2.5 A full description of the variation in waste arisings among households of different types is given in section 6.3. The following discussion summarises in general terms the extent to which the hypotheses set up in Chapter 2 were validated by the experimental findings.

6.2.6 All of the household characteristics investigated, with the exception of 'ownership of a sink disposal unit', were found to be significantly associated ($p < 0.05$) with at least one category of waste. However, the individual household characteristics varied considerably in terms of the number of waste categories with which they were associated. Certain characteristics such as household size and Family

Life Cycle were found to be associated with variation in all, or nearly all, of the waste categories. A second group of characteristics, among them socio-economic group and ownership of a deep freeze, were associated mainly with variation in categories of post-consumer waste, such as kitchen waste and types of waste packaging. A third group of household characteristics were found to be associated only with very specific waste categories. For example 'type of domestic heating' was the only factor apart from 'household size' to be significantly associated with variation in the 'fines' category. Similarly, 'mode of newspaper purchase' was associated with only three categories of waste at the 5% level and only one category, 'newsprint', at the 1% level. In total, out of 300 possible associations between household characteristics and waste arisings (20 household characteristics x 15 categories of waste) 169 were validated at 5% significance.

6.2.7 The results described above rest on the validity of the assumptions on which the F test is based, namely the assumptions of 'normality' and 'homoscedasticity' (i.e. homogeneity of variance among the sub-groups of households) in the statistical distributions. Homoscedasticity is generally tested for by comparing the ratio of highest to lowest mean squares among the subgroups using the appropriate critical values of F (Edwards 1963). This procedure was carried out for selected household characteristics and selected waste categories. In each case the extreme high and low mean squares did not differ significantly from one another, and homogenity of variance was therefore assumed to prevail. However the distributions of waste measurements did not wholly conform to statistically normal distributions, and the underlying assumption of normality was not, therefore, technically valid. However, as has been shown in the discussion in Chapter 5, the most common reason for the departure from normality was the occurence of a relatively small proportion of extreme values at the upper ends of the distributions. Assuming that the F test is generally fairly robust to departures from normality (Robson 1973) then the use of these significance tests is not invalidated. However, in cases where the calculated variance ratios only just exceed the critical values of F, the results of the tests should be interpreted cautiously. These 'marginal cases' account for approximately 8% of the results and are distinguished in Table 6.1 by the fact that a corrected variance ratio is given in each case.

6.3 Variation in Waste Arisings Among Household Types

6.3.1 This section gives a detailed description of the variation in waste arisings among different types of household. The discussion emphasises the variation in waste arisings that was found to be 'significant' i.e. statistically associated with household characteristics at the 5% level. Explanations are also tendered to account for instances where the experimental findings did not confirm a research hypothesis i.e. where a relationship between a particular type of waste and a particular household characteristic was expected but none was found. The discussion is organised in terms of the groups of waste categories identified in Chapter 5, viz:

- kitchen waste
- packaging waste
- newsprint
- garden waste, textiles and 'miscellaneous'
- non-ferrous metals and fines

6.3.2 It is important to bear in mind that although certain of the empirical findings described in the following discussion are interpreted as a substantiation of the research hypotheses, the grouping of waste arisings by an individual characteristic does not provide a direct measure of the effect of that characteristic on waste arisings. To do this it would be necessary to standardise the data in each group to take account of the representation of other factors within the groups. This task is taken up in sections 6.4 to 6.6 where the effects of household characteristics on waste arisings are considered jointly.

Kitchen Waste

6.3.3 The following points summarise the most interesting and statistically significant findings with respect to kitchen waste:

- Significant associations were found between the variation in kitchen waste and all of the household characteristics tested, with the exception of 'smoke control zone', 'ownership of a sink disposal unit' and 'mode of newspaper purchase' or 'weekly magazine purchase'. Of these four factors only 'ownership of a sink disposal unit' was originally hypothesised to be related to variation in kitchen waste.

- Levels of kitchen waste increased progressively with household size from 1.72 kg/hh/wk (one person) to 6.62 kg/hh/wk (seven plus persons). However, the increase in waste was not linearly related to increases in household size. This reflects the economies of scale that occur in providing food for large households, and also the fact that large households usually contain a higher proportion of children whose nutritional needs are on average less than those of adults.

- The level of kitchen waste was found to vary in a parabolic fashion according to successive stages in the Family Life Cycle; low in early stages of the Life Cycle, increasing during the middle phases and declining again in later stages. The highest mean level of kitchen waste coincided with stage 4 in the Family Life Cycle (older married couples with children) in which the family is usually complete and income is likely to be highest and nutritional demands greatest. Figure 6.1 shows the mean levels of kitchen waste associated with stages 1, 3 and 4 in the Family Life Cycle among households with 4 persons (because of the inter-correlation between household size and Family Life Cycle it was not possible to show all stages in the Life Cycle while standardising for household size).

- Average levels of kitchen waste for households which had milk delivered were 3.31 kg/hh/wk as compared to 2.44 kg/hh/wk for those which did not. The association was highly significant ($F = 17.32; 1, 1275$) and may be accounted for by a related preference for canned and convenience food among those households which did not have milk delivered.

- Freezer ownership was found to be strongly associated with variation in kitchen waste ($F = 33.76; 1, 1275$). The higher levels of kitchen waste generated by those households who owned freezers can be explained both in terms of the greater capacity to store fresh fruit and vegetables and carcase meat, and by the tendancy for the economies associated with bulk buying to elevate consumption levels.

- Levels of kitchen waste were found to be lower on average among households in which both adults were working. The differences, though not large, were significant ($F = 3.94; 2, 1274$) and probably reflect the differences in the propensities of the people concerned either to eat out at work or to buy time saving convenience products.

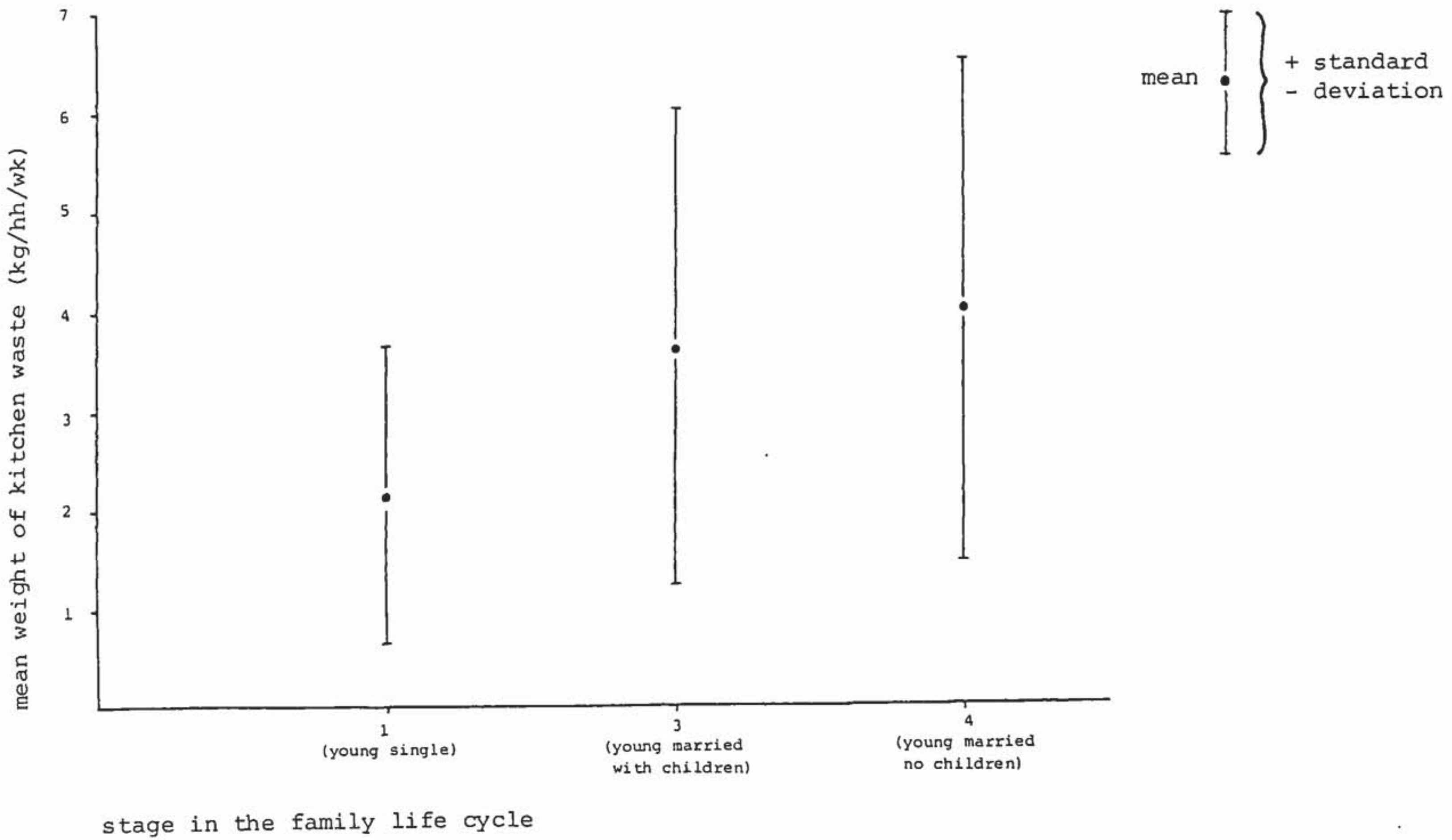

Fig. 6.1 Plot of mean levels of kitchen waste in subgroups of the family life cycle (4 person households)

- There were significant differences in levels of kitchen waste from households grouped according to the occupation of the household head. Levels were similar among groups who were economically active (all between 3 and 4 kg/hh/wk) but fell to just over 2 kg/hh/wk for retired households. Highest levels were associated with the skilled married sector. Although this finding may appear to contradict the hypothesis that food consumption (and hence disposal of kitchen waste) will tend to increase according to income, the findings may be explained either by the existence of a negative correlation between household size and socio-economic group or by a tendancy for higher income groups to buy previously trimmed and prepared foods with less associated waste.

- Contrary to expectations, levels of kitchen waste were higher for pet owners than for non-owners (3.50 kg/hh/wk as compared to 2.96 kg/hh/wk). It was originally hypothesised that pets might act as an 'alternative' to the dustbin for the disposal of kitchen scraps and that lower levels of kitchen waste would therefore be generated by households owning pets. The reversal of this hypothesis may be due to the fact that many small or single person families living in multi-storey flats were absent from the pet-owner group as a result of rules disallowing pets in this type of accommodation.

- Significant differences were found between levels of kitchen waste from households grouped according to property type and tenure. The highest mean levels of kitchen waste were generated by owner occupied and detached households, and the lowest mean levels were generated by private rented, multi-occupancy flats. The differences reflect the correlation between type of dwelling and household size and socio-economic group. They may also reflect the fact the residents of multistorey flats do not have access to garden or allotment space for growing fresh vegetables.

Packaging Waste

6.3.4 Significant associations were found between the variation in packaging wastes and household size, Family Life Cycle, occupation of household head, property type, and car and freezer ownership. These are summarised as follows:

- The most powerful explanatory variable (measured in terms of calculated variance ratios) in relation to all types of packaging waste with the exception of ferrous metals, was household size. Levels of packaging waste were between three and five times as high from households of seven plus persons as compared to single person households.

- An exceptionally strong association ($F = 42.43; 1, 1275$) was observed between variation in ferrous metals and pet ownership. This phenomenon is explained by the fact that a high proportion of waste in the ferrous category consisted of pet food tins.

- Significant differences were found between levels of packaging waste from households grouped according to stages in the Family Life Cycle. The relationship between quantities of waste packaging and Family Life Cycle was parabolic and similar to the relationship between Family Life Cycle and kitchen waste. The highest mean levels were associated with stage 4 in the Life Cycle (older married couples with children). This pattern is consistent with the Life Cycle theory of consumption which asserts that the purchase of consumer goods, and by implication the disposal of packaging waste, will tend to peak at middle age.

- An interesting feature of the differences in levels of waste packaging between stages in the Life Cycle (shown in Table 6.2) is that 'young single people' generate greater amounts of packaging than their young married counterparts, although the latter generate more waste in total. One possible explanation is that with no division of labour in single person households less time is spent cooking with the result that more highly packaged convenience foods tend to replace fresh foods in the diet. This explanation is reinforced by the fact that single person households generate less kitchen waste than households of young married couples. Levels of packaging waste decline sharply during stages 5 and

Table 6.2 Variation in Mean Levels of Packaging Wastes (kg/hh/wk) between Households Grouped According to Stage in the Family Life Cycle

CATEGORY OF PACKAGING WASTE	STAGE IN FAMILY LIFE CYCLE					
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Scrap Paper etc.	0.62	0.60	0.84	0.95	0.52	0.35
Cardboard	0.47	0.50	0.73	0.75	0.39	0.24
Ferrous	0.60	0.56	0.70	0.78	0.50	0.30
Glass	1.32	1.28	1.11	1.16	0.75	0.48
Plastic film	0.37	0.29	0.34	0.36	0.20	0.14
Dense plastic	0.19	0.24	0.27	0.30	0.19	0.12
All packaging	3.57	3.47	3.99	4.30	2.55	1.63

6 of the Family Life Cycle (older couples with no children living with them and 'solitary survivors'), reaching a minimum which represents less than half the peak level generated during stage 4 in the Life Cycle.

- Total levels of waste packaging were 3.71 kg/hh/wk for freezer owners compared to 2.80 kg/hh/wk for non-owners. This difference overturns the research hypothesis connecting freezer ownership with the disposal of packaging waste. The original premise was that the purchase of foods in bulk for freezing would reduce the amount of packaging per unit quantity of food. The experimental findings suggest that if any such conservation of packaging occurs, it is more than offset by an overall increase in food consumption. This may be explained by an intervening relationship between freezer ownership and household size.

- Significant differences were found between levels of packaging waste from households grouped by car ownership. The trend of increasing levels of packaging waste according to the number of cars owned by the household can be explained partly in terms of the concealed effect of household size (the correlation coefficient between car ownership and household size was 0.35). Nevertheless the same trend persisted among groups of households standardised for household size, as illustrated in Figure 6.2.

- Levels of all types of packaging waste were found to increase in direct relation to increases in the socio-economic status of the head of household. The highest levels of packaging waste were generated by professional households, and the lowest levels by economically inactive households. Glass was exceptional in the sense that the second highest levels were generated by the 'student/other inactive' group. The maximum level of packaging among all socio-economic groups was approximately double the minimum level for nearly all types of packaging waste.

- Households in <u>different types of property</u> were found to generate significantly different amounts of packaging. Levels of packaging waste were highest from households in detatched properties, declining with property status, through semi-detatched and terraced properties to a minimum from households in multi-storey and multi-occupancy flats. Once again, glass deviated from this pattern and the second highest levels of glass were generated by households in multi-occupancy flats. This is consistent with the tendancy for 'bedsit' type accommodation to be occupied by a higher than average proportion of residents in the 'student/other inactive' group.

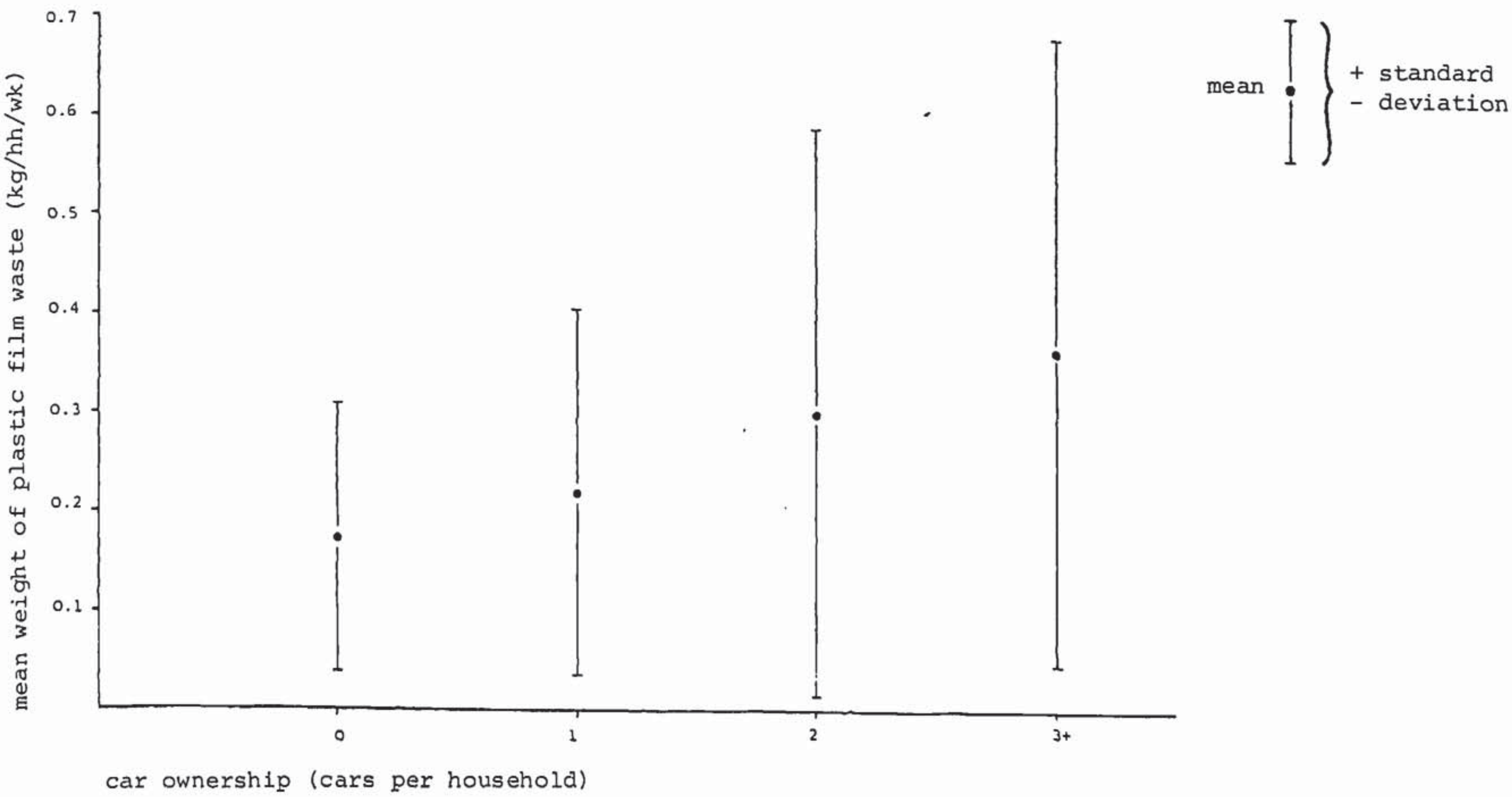

Fig. 6.2 <u>Plot of mean levels of plastic film waste in subgroups of car ownership (7+ person households)</u>

Newsprint

6.3.5 It was hypothesised that the quantity of waste newsprint generated by a households would be largely a function of Family Life Cycle, socio-economic group and whether or not the household had a newspaper delivered. Although the variation in waste newsprint was found to be significantly associated with all three factors, the differences in levels of newsprint were small in each case. The main findings are summarised as follows:

- Levels of newsprint were highest for households which took delivery of a daily newspaper (1.44 kg/hh/wk) and less for those households which either bought a newspaper over the counter (1.20 kg/hh/wk) or did not buy a newspaper regularly (0.88 kg/hh/wk).

- Among socio-economic groups the highest levels of newsprint were generated by 'skilled manual' households (1.88 kg/hh/wk) and the lowest levels were generated by 'retired' households (1.06 kg/hh/wk). It is notable that, in contrast to most other types of waste, there was relatively little difference in levels of newsprint between retired households and those which were economically active. The relatively weak associations between household characteristics and variation in newsprint can be explained partly by the fact that systematic influences on newspaper purchase are obscured by the diversity in the alternative ways of disposing of waste newsprint (e.g. through charity or local authority waste paper collections).

Garden Waste, Textiles and 'Miscellaneous' Waste

6.3.6 Garden waste was found to be significantly associated with property type, property size (measured in terms of number of bedrooms), tenure and Family Life Cycle. The first three of these factors are indicators of 'access to garden' and 'size of garden'. In summary the main findings are:

- Differences in levels of garden waste were particularly marked between households grouped according to property size, varying from 0.3 kg/hh/wk (one bedroom households) to 2.1 kg/hh/wk (households with six or more bedrooms). The possibility of property size acting as a surrogate for household size in this context is ruled out since garden waste was one of only two waste categories found not to be significantly associated with household size.

- The variation in garden waste between stages in the Family Life Cycle is interesting because it departs from the usual pattern of 'peaking' in middle years. The highest levels of garden waste were generated by older married couples with no children living with them (0.92 kg/hh/wk) and the second highest levels were generated by older single people (0.59 kg/hh/wk). Both groups consist largely of retired people and the high waste levels probably reflect a greater amount of time spent gardening. By far the lowest levels of garden waste were found among young single groups (0.09 kg/hh/wk: equivalent to one tenth of the highest mean level) who lack either access to gardens or else the motivation to spend time gardening.

6.3.7 Significant associations were found between the variation in textile waste and household size, Family Life Cycle, occupation of household head and car ownership. Contrary to expectations there was no evidence that the balance of sexes within the household affected the quantity of textiles discarded. The main findings were:

- Levels of textile waste increased according to household size, but at a less than proportional rate. This may be explained by economies of scale in clothing purchase through the practice of 'handing-down' clothes. Among socio-economic groups, the highest levels of textile waste were generated by professional households (0.58 kg/hh/wk) and the lowest levels were generated by retired households (0.17 kg/hh/wk) although there was no clearly defined gradient between these two extremes.

- The pattern of variation in levels of textile waste between households grouped according to stages in the Family Life Cycle was similar to the corresponding pattern in levels of kitchen and packaging waste, with peak levels generated at stage 4 in the Life Cycle. No plausible explanation is offered for the apparent association between textile waste and 'type of domestic heating' except that 'type of heating' may have been acting as an intervening variable for other factors in this context.

6.3.8 No evidence of strong systematic associations was expected between '<u>miscellaneous</u>' waste and household characteristics, since this type of waste is, almost by definition, the product of sporadic or idiosynchratic behaviour by households. In practice, associations were found between miscellaneous waste and several household characteristics including property type, tenure, Family Life Cycle and household size. However, except in the case of household size, the associations were only just significant and no particular patterns or trends were apparent among the sub-groups. Miscellaneous non-combustible waste was not significantly associated with household size and with no other household characteristics except Family Life Cycle and (after correction for random error) with freezer ownership.

<u>Non-Ferrous Metals and Fines</u>

6.3.9 Significant differences were found in the levels of non-ferrous metals between households grouped according to househld size, Family Life Cycle, occupation of household head and freezer ownership. In summary:

- The most marked contrasts were observed between <u>households grouped by their size</u>. The average level of non-ferrous metals generated by single person households was 0.03 kg/hh/wk as compared to an average level of 0.12 kg/hh/wk generated by households of seven or more persons.

- The variation in fines was found to be strongly associated with '<u>type of domestic heating</u>' ($F = 55.06; 1, 1275$). The association is reflected in the distinct differences in levels of fines between those households with solid fuel heating (1.29 kg/hh/wk) and those households without (0.40 kg/hh/wk). Surprisingly, no significant differences in levels of fines were found between households inside and outside smoke control zones. This can be explained by the fact that households sampled in inner city areas covered by smoke control orders often burned smokeless fuel (thereby generating ash); the overall levels of fines from these areas were therefore as high as from the suburbs where, although there were no smoke restrictions, gas or oil-fired central heating was more common.

<u>Total Waste</u>

6.3.10 Significant associations were found between the variation in total waste and all household characteristics recorded by the questionnaire, with the exception of 'mode of newspaper purchase', 'ownership of a sink disposal unit' and 'frequency of shopping trips'. Figures 6.3 to 6.6 illustrate the distributions of levels of total waste within subgroups of households classified according to four household characteristics: household size, Family Life Cycle, occupation of the head of household and tenure. The main points are:

- The mean levels of total waste varied according to household size, from a minimum of 5.81 kg/hh/wk (one person households) to a maximum of 20.10 kg/hh/wk (households with seven or more persons). The increase in total waste levels was less than proportional to household size reflecting the effects of the various types of 'economies of scale' discussed in the context of individual component categories of waste.

- Levels of total waste varied in a parabolic fashion according to successive stages in the Family Life Cycle, increasing from stage 1 ('young single people') to a maximum at stage 4 ('older married couples with children') and subsequently declining to a minimum at stage 6 ('solitary survivours'). This pattern is consistent with the variation in kitchen waste and packaging waste between households at different stages in the Life Cycle.

- The most distinct differences in levels of total waste between groups of households classified by occupation of household head, were between the 'economically active' groups and the 'economically inactive' groups with mean levels of (11.59) kg/hh/wk and (8.56) kg/hh/wk respectively.

- Variation in total waste was significantly associated with both property type and tenure. The highest levels of total waste were generated by detatched owner-occupied properties while multi-storey flats and private rented dwellings generated the lowest levels of total waste.

6.3.11 It is interesting to note that the calculated variance ratios shown in Table 6.1 indicate that the statistical associations between total waste and household characteristics are generally stronger than the associations between individual components of waste and household characteristics. This can be explained by two factors:

(1) There was no sorting error involved in the measurement of total waste levels.

(2) Random weekly variations in the levels of individual waste components will tend to cancel out, resulting in a smaller proportional element of random variation in levels of total waste.

Summary

6.3.12 This section has given a detailed descriptive account of the quantity and composition of waste arisings generated by households of different types. The strength and direction

a

```
ONE PERSON    x = 5.81   σ = 4.46   n = 195

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
  0.00        9     *********
  2.00       46     **********************************************
  4.00       42     ******************************************
  6.00       47     ***********************************************
  8.00       20     ********************
 10.00        9     *********
 12.00       11     ***********
 14.00        2     **
 16.00        1     *
 18.00        3     ***
 20.00        0
 22.00        4     ****
 24.00        0
 26.00        1     *
```

b

```
TWO PERSONS    x = 8.73   σ = 5.06   n = 461
 EACH * REPRESENTS    2 OBSERVATIONS
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
  0.00        6     ***
  2.00       25     *************
  4.00       58     *****************************
  6.00       97     *************************************************
  8.00       92     **********************************************
 10.00       71     ************************************
 12.00       38     *******************
 14.00       34     *****************
 16.00       16     ********
 18.00        3     **
 20.00        5     ***
 22.00        6     ***
 24.00        3     **
 26.00        3     **
 28.00        2     *
 30.00        0
 32.00        0
 34.00        1     *
 36.00        0
 38.00        0
 40.00        0
 42.00        1     *
```

Fig. 6.3 Distribution of total waste arisings in subgroups of household size c

```
THREE PERSONS   x = 10.02  σ = 5.24  n = 194

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   0.00        2    **
   2.00        7    *******
   4.00       15    ***************
   6.00       33    *********************************
   8.00       38    **************************************
  10.00       35    ***********************************
  12.00       25    *************************
  14.00        9    *********
  16.00        8    ********
  18.00        9    *********
  20.00        3    ***
  22.00        4    ****
  24.00        4    ****
  26.00        0
  28.00        2    **
```

d

```
FOUR PERSONS   x = 12.04  σ = 6.03  n = 197

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   0.00        3    ***
   2.00        1    *
   4.00       12    ************
   6.00       22    **********************
   8.00       21    *********************
  10.00       40    ****************************************
  12.00       22    **********************
  14.00       23    ***********************
  16.00       19    *******************
  18.00       12    ************
  20.00        7    *******
  22.00        6    ******
  24.00        3    ***
  26.00        1    *
  28.00        1    *
  30.00        2    **
  32.00        1    *
  34.00        0
  36.00        0
  38.00        0
  40.00        1    *
```

Fig. 6.3 (continued) Distribution of total waste arisings in subgroups of household size e

FIVE PERSONS x = 13.51 σ = 6.50 n = 145

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	1	*
2.00	2	**
4.00	6	******
6.00	10	**********
8.00	13	*************
10.00	17	*****************
12.00	27	***************************
14.00	19	*******************
16.00	12	************
18.00	19	*******************
20.00	4	****
22.00	6	******
24.00	2	**
26.00	3	***
28.00	0	
30.00	0	
32.00	1	*
34.00	0	
36.00	1	*
38.00	1	*
40.00	0	
42.00	1	*

f

SIX PERSONS x = 16.67 σ = 7.38 n = 49

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	0	
2.00	0	
4.00	2	**
6.00	3	***
8.00	5	*****
10.00	4	****
12.00	1	*
14.00	6	******
16.00	4	****
18.00	4	****
20.00	5	*****
22.00	3	***
24.00	3	***
26.00	5	*****
28.00	2	**
30.00	1	*
32.00	1	*

g

SEVEN PLUS PERSONS x = 20.10 σ = 12.75 n = 30

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	0	
2.00	0	
4.00	3	***
6.00	1	*
8.00	2	**
10.00	0	
12.00	2	**
14.00	3	***
16.00	5	*****
18.00	2	**
20.00	1	*
22.00	2	**
24.00	1	*
26.00	0	
28.00	1	*
30.00	2	**
32.00	0	
34.00	2	**
36.00	0	
38.00	0	
40.00	1	*
42.00	0	
44.00	0	
46.00	0	
48.00	0	
50.00	1	*
52.00	0	
54.00	1	*

Fig. 6.3 (continued) <u>Distribution of total waste arisings in subgroups of household size</u>

a

YOUNG SINGLE x = 8.37 σ = 6.96 n = 29

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	2	**
2.00	2	**
4.00	9	*********
6.00	3	***
8.00	2	**
10.00	3	***
12.00	2	**
14.00	2	**
16.00	0	
18.00	1	*
20.00	0	
22.00	2	**
24.00	0	
26.00	0	
28.00	1	*

b

YOUNG MARRD NO CHILDREN x = 10.31 σ = 7.35 n = 54

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	2	**
2.00	4	****
4.00	4	****
6.00	8	********
8.00	9	*********
10.00	8	********
12.00	3	***
14.00	5	*****
16.00	4	****
18.00	1	*
20.00	2	**
22.00	1	*
24.00	1	*
26.00	0	
28.00	1	*
30.00	0	
32.00	0	
34.00	0	
36.00	0	
38.00	0	
40.00	0	
42.00	1	*

c

YOUNG MRRD WITH CHILDREN x = 11.62 σ = 6.24 n = 202

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	2	**
2.00	7	*******
4.00	10	**********
6.00	24	************************
8.00	25	*************************
10.00	38	**************************************
12.00	31	*******************************
14.00	24	************************
16.00	10	**********
18.00	12	************
20.00	2	**
22.00	4	****
24.00	5	*****
26.00	1	*
28.00	2	**
30.00	2	**
32.00	2	**
34.00	0	
36.00	0	
38.00	0	
40.00	1	*

Fig. 6.4 Distribution of total waste arisings in subgroups of the family life cycle

d

```
OLDER MRRD WITH CHILDREN    x = 12.76   σ = 7.27   n = 252

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
    0.00         2     **
    2.00         2     **
    4.00        19     *******************
    6.00        28     ****************************
    8.00        33     *********************************
   10.00        37     *************************************
   12.00        28     ****************************
   14.00        20     ********************
   16.00        23     ***********************
   18.00        24     ************************
   20.00        10     **********
   22.00         9     *********
   24.00         4     ****
   26.00         6     ******
   28.00         1     *
   30.00         0
   32.00         1     *
   34.00         1     *
   36.00         1     *
   38.00         1     *
   40.00         0
   42.00         0
   44.00         0
   46.00         0
   48.00         0
   50.00         1     *
   52.00         0
   54.00         1     *
```

e

```
OLDER MARRIED NO CHILDREN    x = 8.41   σ = 4.45   n = 361
 EACH * REPRESENTS    2 OBSERVATIONS
 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
    0.00         5     ***
    2.00        18     *********
    4.00        50     *************************
    6.00        78     ***************************************
    8.00        72     ************************************
   10.00        54     ***************************
   12.00        32     ****************
   14.00        28     **************
   16.00        10     *****
   18.00         2     *
   20.00         3     **
   22.00         6     ***
   24.00         0
   26.00         2     *
   28.00         1     *
```

Fig. 6.4 (continued) Distribution of total waste arisings in subgroups of the family life cycle f

```
OLDER SINGLE   x = 5.72  σ = 4.23  n = 184

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   0.00       7     *******
   2.00      44     ********************************************
   4.00      39     ***************************************
   6.00      46     **********************************************
   8.00      22     **********************
  10.00       9     *********
  12.00       9     *********
  14.00       0
  16.00       1     *
  18.00       3     ***
  20.00       0
  22.00       3     ***
  24.00       0
  26.00       1     *
```

Fig. 6.4 (continued) <u>Distribution of total waste arisings in subgroups of the family life cycle</u>

a

PROFESSIONAL $\bar{x}$ = 12.78 σ = 8.36 n = 54

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	1	*
2.00	0	
4.00	4	****
6.00	6	******
8.00	7	*******
10.00	11	***********
12.00	7	*******
14.00	2	**
16.00	5	*****
18.00	2	**
20.00	1	*
22.00	4	****
24.00	0	
26.00	1	*
28.00	0	
30.00	0	
32.00	1	*
34.00	1	*
36.00	0	
38.00	0	
40.00	0	
42.00	0	
44.00	0	
46.00	0	
48.00	0	
50.00	1	*

b

INTERMEDIATE $\bar{x}$ = 11.10 σ = 5.69 n = 136

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	1	*
2.00	3	***
4.00	12	************
6.00	20	********************
8.00	14	**************
10.00	29	*****************************
12.00	16	****************
14.00	9	*********
16.00	13	*************
18.00	9	*********
20.00	3	***
22.00	5	*****
24.00	1	*
26.00	2	**
28.00	2	**

c

SKILLED NONMANUAL $\bar{x}$ = 12.29 σ = 7.46 n = 106

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	2	**
2.00	4	****
4.00	7	*******
6.00	13	*************
8.00	14	**************
10.00	12	************
12.00	11	***********
14.00	12	************
16.00	8	********
18.00	7	*******
20.00	2	**
22.00	7	*******
24.00	0	
26.00	1	*
28.00	3	***
30.00	1	*
32.00	0	
34.00	0	
36.00	1	*
38.00	0	
40.00	0	
42.00	1	*

Fig. 6.5 Distribution of total waste arisings in subgroups of occupation of the household head

d

SKILLED MANUAL $x = 11.89$ $\sigma = 6.89$ $n = 253$

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	4	****
2.00	6	******
4.00	18	******************
6.00	32	********************************
8.00	36	************************************
10.00	33	*********************************
12.00	34	**********************************
14.00	31	*******************************
16.00	13	*************
18.00	15	***************
20.00	7	*******
22.00	5	*****
24.00	6	******
26.00	5	*****
28.00	1	*
30.00	2	**
32.00	1	*
34.00	1	*
36.00	0	
38.00	0	
40.00	2	**
42.00	1	*

e

PARTLY SKILLED $x = 9.88$ $\sigma = 5.50$ $n = 78$

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	2	**
2.00	4	****
4.00	7	*******
6.00	8	********
8.00	15	***************
10.00	19	*******************
12.00	7	*******
14.00	3	***
16.00	3	***
18.00	3	***
20.00	2	**
22.00	3	***
24.00	1	*
26.00	1	*

f

UNSKILLED $x = 11.27$ $\sigma = 8.62$ $n = 19$

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	0	
2.00	3	***
4.00	1	*
6.00	3	***
8.00	3	***
10.00	0	
12.00	1	*
14.00	3	***
16.00	2	**
18.00	1	*
20.00	0	
22.00	0	
24.00	0	
26.00	0	
28.00	0	
30.00	1	*
32.00	1	*

Fig. 6.5 (continued) Distribution of total waste arisings in subgroups of occupation of the household head

g

```
UNEMPLOYED   x = 10.30   σ = 7.04   n = 161

 MIDDLE OF   NUMBER OF
 INTERVAL    OBSERVATIONS
   0.00       1    *
   2.00      11    ***********
   4.00      23    ***********************
   6.00      22    **********************
   8.00      20    ********************
  10.00      20    ********************
  12.00      25    *************************
  14.00      12    ************
  16.00       9    *********
  18.00       4    ****
  20.00       4    ****
  22.00       1    *
  24.00       3    ***
  26.00       2    **
  28.00       2    **
  30.00       0
  32.00       0
  34.00       0
  36.00       0
  38.00       1    *
  40.00       0
  42.00       0
  44.00       0
  46.00       0
  48.00       0
  50.00       0
  52.00       0
  54.00       1    *
```

h

```
RETIRED   x = 7.42   σ = 4.79   n = 371
 EACH * REPRESENTS   2 OBSERVATIONS
 MIDDLE OF   NUMBER OF
 INTERVAL    OBSERVATIONS
   0.00      10    *****
   2.00      45    ***********************
   4.00      57    *****************************
   6.00      89    *********************************************
   8.00      70    ***********************************
  10.00      41    *********************
  12.00      17    *********
  14.00      17    *********
  16.00       6    ***
  18.00       6    ***
  20.00       5    ***
  22.00       5    ***
  24.00       0
  26.00       1    *
  28.00       0
  30.00       1    *
  32.00       0
  34.00       1    *
```

i

```
OTHER INACTIVE/STUDENTS   x = 9.79   σ = 5.47   n = 87

 MIDDLE OF   NUMBER OF
 INTERVAL    OBSERVATIONS
   0.00       0
   2.00       5    *****
   4.00      10    **********
   6.00      19    *******************
   8.00      12    ************
  10.00      11    ***********
  12.00       9    *********
  14.00       5    *****
  16.00       6    ******
  18.00       4    ****
  20.00       1    *
  22.00       1    *
  24.00       4    ****
```

Fig. 6.5 (continued) Distributions of total waste arisings in subgroups of occupation of the household head

a

OWNER OCCUPIED x = 10.86 σ = 6.62 n = 762
EACH * REPRESENTS 5 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	12	***
2.00	30	******
4.00	71	***************
6.00	122	*************************
8.00	108	**********************
10.00	108	**********************
12.00	82	*****************
14.00	67	**************
16.00	47	**********
18.00	38	********
20.00	18	****
22.00	19	****
24.00	9	**
26.00	10	**
28.00	6	**
30.00	4	*
32.00	2	*
34.00	3	*
36.00	1	*
38.00	1	*
40.00	2	*
42.00	1	*
44.00	0	
46.00	0	
48.00	0	
50.00	1	*

b

HOUSING ASSOCIATION x = 10.38 σ = 7.10 n = 88
EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	5	***
2.00	37	*******************
4.00	48	************************
6.00	76	**************************************
8.00	57	*****************************
10.00	46	***********************
12.00	28	**************
14.00	18	*********
16.00	12	******
18.00	11	******
20.00	5	***
22.00	8	****
24.00	4	**
26.00	2	*
28.00	1	*
30.00	1	*
32.00	1	*
34.00	0	
36.00	0	
38.00	0	
40.00	0	
42.00	0	
44.00	0	
46.00	0	
48.00	0	
50.00	0	
52.00	0	
54.00	1	*

Fig. 6.6 Distribution of total waste arisings in subgroups of property tenure

c

COUNCIL RENTED $x = 8.77$ $\sigma = 6.03$ $n = 361$

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	3	***
2.00	9	*********
4.00	11	***********
6.00	4	****
8.00	10	**********
10.00	17	*****************
12.00	10	**********
14.00	7	*******
16.00	5	*****
18.00	3	***
20.00	2	**
22.00	2	**
24.00	2	**
26.00	1	*
28.00	1	*
30.00	0	
32.00	0	
34.00	0	
36.00	0	
38.00	0	
40.00	0	
42.00	1	*

d

OTHER RENTED $x = 8.36$ $\sigma = 4.77$ $n = 66$

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	1	*
2.00	5	*****
4.00	10	**********
6.00	11	***********
8.00	17	*****************
10.00	6	******
12.00	7	*******
14.00	4	****
16.00	2	**
18.00	0	
20.00	0	
22.00	2	**
24.00	1	*

Fig. 6.6 (continued) Distribution of total waste arisings in subgroups of property tenure

of the associations between individual household characteristics and each category of waste has been established. The next section pursues the search for causal relationships (as distinct from statistical associations) connecting household characteristics with waste arisings, in order to establish the 'model development' process on a theoretically sound footing.

6.4 Model Development

6.4.1 This section discusses the alternative approaches to the statistical modelling of waste arisings at the household level and puts forward two forms of model to explain and predict waste arisings. These are firstly a regression model based on synthetic, composite variables called principle components, and secondly a category model based on a subset of the basic household characteristics.

6.4.2 Lee (1973) has identified a number of discrete stages in model development: selection of variables to be included; choice of appropriate level of aggregation and categorisation; specification and calibration. The first two of these stages were dealt with in Chapter 2 of this thesis. The third stage, model specification, involves the translation of the various model components (in this case the set of household characteristics plus the dependent, waste arisings) into a form which adequately describes how all of the components interact with one another.

6.4.3 In this research the process of model specification was undertaken within a framework of decision criteria relating to:

(1) Theoretical issues
(2) Practical issues.

These are described below:

Theoretical Issues

(1) Validity concerns how faithfully the model represents the theoretical constructs and the relationships between the constructs.

(2) Robustness concerns the stability of the relationships in the model. Robustness does not affect the usefulness of the model as a descriptive device but is of crucial importance when the model is used for prediction or generalisation, as in this research.

(3) Goodness of fit concerns the ability of the model to reproduce the behaviour of its real world counterpart within acceptable limits of tolerance, or error.

Practical Issues

(4) Parsimony concerns the conciseness of the model. In order to be managable and comprehensible the model should be 'less

complicated than reality (and) easier to manipulate and carry about than the real thing' (Ackoff 1969).

(5) Availability of estimates of independent variables. This affects the usefulness of the model in terms of its ability to predict the dependent in unsurveyed areas and at future points in time.

Reference is made to this set of criteria throughout the remainder of this chapter both in the context of model design and in the context of model evaluation.

6.4.4 There are a number of basic forms of statistical model designed to explain and predict a dependent variable from a set of explanatory variables. The alternative approaches involve:

(1) Specifying combinations of the explanatory variables on an 'a priori' basis, then estimating the level of the dependent variable within each cell by simple tabulation. This approach is known as a category model.

(2) Specifying the explanatory variables separately and estimating their relationships with the dependent variable using multiple regression analysis.

(3) Specifying the fundamental constructs underlying combinations of the explanatory variables, and

relating the dependent variable to these constructs as opposed to the basic variables.

6.4.5 Of these alternative approaches, the second approach based on the regression of 'basic' variables is perhaps the most widely used as an analytical device. *However there are* a number of statistical problems involved in using conventional regression analysis for modelling household waste arisings. These can be summarised under the headings of 'intercorrelation' and 'interaction'.

- <u>Intercorrelation</u>

This gives rise to 'multicollinearity' which frustrates attempts to determine the separate effects of the explanatory variables on the dependent, waste arisings. It results in high standard errors associated with the regression coefficients. If there is clear evidence of logical priorities among explantory variables, the problem can be overcome by excluding one of a pair of highly correlated variables from the analysis. However, in practice, evidence of logical priorities is frequently unavailable. The penalty for excluding a variable which is causally related to the dependent is to include bias in the coefficients of the remaining explanatory variables. Table 6.3 shows selected correlations between variables in a simple 10 by 10 matrix. The high degree of intercorrelation between the variables indicates that any attempt to simultaneously

Table 6.3 Correlations Between Ten Selected Household Characteristics

	Detatched owner-occupied dwellings	Private rented multi-occupancy flats	Socioeconomic groups AB	Head of household retired	Freezer ownership	Car ownership	Household size	Stage 1 Family Life Cycle (young single)	Stage 4 Family Life Cycle (the complete family)	Stage 6 Family Life Cycle (solitary survivors)
Detatched owner-occupied dwellings	1.0		0.31							
Private rented multi-occupancy flats		1.0						0.38		
Socio-economic groups AB	0.31		1.0			0.35				
Head of household retired				1.0			-0.45			0.39
Freezer ownership					1.0		0.36			
Car ownership			0.35			1.0	0.35			
Household size				-0.45	0.36	0.35	1.0		0.46	-0.50
Stage 1 Family Life Cycle (young single)		0.38						1.0		
Stage 4 Family Life Cycle (the complete family)							0.46		1.0	
Stage 6 Family Life Cycle (solitary survivors)				0.39			-0.50			1.0

regress the variables would lead to difficulties in determining the significance of the regression coefficients. For example, stage 1 in the Family Life Cycle ('young single') is positively correlated with 'private rented multi-occupancy flats'. There are positive correlations between 'socio-economic groups AB' and 'detatched owner-occupied dwellings,' and between 'freezer ownership' and 'car ownership'. 'Household size' is negatively correlated with stage 6 in the Family Life Cycle ('solitary survivors') but positively correlated with stage 4 in the Life Cycle ('the complete family') and also with freezer ownership and car ownership.

- Interaction

Interaction is said to occur when the effect of an explanatory variable on the dependent is governed by the condition of other variables in the analysis. Where there is interaction the assumption of additivity in the regression equation is invalid. Interaction can be overcome by introducing cross-product terms into the analysis; when however, as in this case, there are a large number of variables and a large number of categories associated with each variable, the number of cross-product terms increases rapidly and the model quickly becomes unmanageable or overdetermined (i.e. too few degrees of freedom for the number of variables). There is no reason to believe that interaction will not be present among the set of household characteristics being tested. For example, it is quite probable that the variation in waste arisings among socio-economic groups will be different at different *stages in the* Family Life Cycle.

6.4.6 Because of the problems described above the conventional regression approach model type (2) was rejected in favour of the two alternative model designs based on model type (1) (categories of household) and model type (3) (synthetic composite variables). Each design is characterised by its own particular strengths and weaknesses in terms of the criteria set out in 6.4.3 and each approach was therefore pursued separately. Both forms of model were developed on the basis of measurements of absolute weight of waste as opposed to measurements of percentages. This was because restrictions on time and computing facilities made it necessary to make a choice regarding the way in which the data was expressed. Measurements of absolute weight are a more fundamental and descriptive form of data than measurements of percentages, and so the former were used as a basis for developing the waste models. The two following sections describe the separate approaches to household waste modelling in terms of the underlying principles, the statistical methodology used to calibrate the models, and the results obtained. Model type (3) (principal components) is examined first in section 6.5, followed by model type (1) (household categories) in section 6.6.

6.5 Waste Arisings Model Based on Principal Components

6.5.1 Principal components analysis is a statistical technique for investigating the structure of multivariate data by identifying underlying dimensions on the basis of inter-correlations among variables. The variation between individuals which is originally expressed in terms of scores observed on a number of variables is re-expressed in terms of a set of derived variables which are compounds of the initial data. Principal components have a number of advantages over unmodified variables as the basic elements of a regression analysis:

(1) They are uncorrelated with one another.

(2) They are more closely represent underlying constructs than the original variables and it is therefore less likely that there will be interaction between them (although the fact that the principal components are mutually uncorrelated does not necessarily imply that they will be mutually independent).

(3) They summarise a wider range of data and thefore conform more closely to the scientific principle of parsimony.

6.5.2 These advantages mean that a model based on principal components will serve as a useful explanatory device and a diagnostic tool by which to understand more clearly the process of waste generation at the household level.

However, the approach is unsuited to the practical needs of a waste estimation method since the principal components are not themselves directly observable, measurable or replicable. This type of model is therefore confined to the data set on which it is calibrated; it cannot be used for making estimates of waste arisings in unsurveyed areas or at future points in time.

Methodology

6.5.3 A computerised principal components routine was applied to a subset of the household variables covered by the questionnaire. Variables were selected for inclusion in the analysis on the basis of their relationship with waste arisings as determined by the one way analysis of variance described in section 6.2. A complete list of the variables selected is given in Table 6.4. The parameters of the computer routine were set so that all principal components with eigenvalues[1] greater than 1.2 were selected for rotation by the varimax technique[2]. Six principal components were found jointly to account for 52% of the variance in the data set. These six components were taken as the basis for the subsequent regression analysis.

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1 In this context eigenvalues represent measures of the amount of variance explained by a particular principle component and hence are measures of the usefulness of the principle component at summarising variation in the data on household characteristics.

2 Rotation is a process of translating the principal components solution into a simpler and more parsimonious end product without violating the statistical properties of the original solution. 'Varimax' is the most widely used method of rotation. It maintains the orthogonal structure (i.e. the principal components remain uncorrelated) while simplifying the way in which the principal components are expressed in terms of the basic variables.

The principal components can be interpreted by reference to the degree to which the original variables are 'loaded' on to the components. In the following account, 'high' loading or weighting refers to a correlation between the original variable(s) and the principal component of $\pm$ 0.5.

6.5.4 Table 6.5 is a summary of the six principal components and their variable loadings. The first component is a summary of variables which are correlated with 'household size'. It gives high positive weighting to car ownership, membership of socio-economic groups C1 and C2 and household size, and negative loading to stage 6 in the Family Life Cycle ('solitary survivors') and retired groups. The second component is representative of 'youth, singleness and full-time education'. It gives high positive weighting to 'private rented multi-occupancy flats', 'students' and stage 1 in the Family Life Cycle. 'Owner occupied detatched dwellings' and 'socio-economic groups AB' load highly on the third principal component which can be interpreted as a general index of 'wealth'. The fourth principal component represents a contrast between 'the complete family' (stage 4 in the Family Life Cycle) and older couples who have no children living with them (stage 5 in the Family Life Cycle). The fifth component is a direct measure of different types of tenure among semi-detatched dwellings. The sixth component is an indicator of 'less well-off families' and gives high positive weighting to married couples with young children (stage 3 in the Family Life Cycle) and local authority provided multistorey accommodation.

6.5.5 Having extracted the six major components, individual households in the data set were given 'component scores' by weighting the original variable scores according to the loading of the variables on the components. Measurements of each household's waste arisings were then regressed against its component scores to obtain a series of regression equations; one for each category of waste. It is acknowledged that in this type of analaysis it is possible for the dependent variable to be significantly correlated with one of the principal components discarded at the first step. However, a preliminary 'diagnostic' principal components analysis on both the set of explanatory variables and the dependent variable indicated that, in general, waste arisings were loaded most highly on the six major components.

6.5.6 The regression of each of the 15 categories of waste against the six major components was run at a 5% significance level using a computerised regression routine. The results of the analysis are given in Table 6.6. For each of the 15 equations the table shows the standardised partial regression coefficients, the multiple correlation coefficient (R) the coefficient of determination (R^2) and the adjusted R^2 (see paragraph 6.5.11) plus the 'residual error'.

Results

6.5.7 All of the six major principal components were found to account for a statistically significant proportion of the variation in at least one category of household waste. The principal component denoting 'household size' was positively correlated with all categories of waste except garden waste and miscellaneous non-combustible waste. The 'young/single' component was negatively correlated with kitchen waste but positively correlated with plastic film and glass. The principal component representing 'wealth' was positively correlated with garden waste and also with three types of packaging waste: paper, glass and plastic film. The principal component denoting 'families' was positively correlated with all types of packaging waste, with the exception of dense plastic, and also with garden and miscellaneous type waste. The 'tenure' component was statistically significant in the case of only one waste category, cardboard, with which it was negatively correlated. The principal component describing less well off groups was negatively correlated with all waste categories where it was significant, viz: garden waste, paper, newsprint and fines.

6.5.8 The proportion of variance explained by the regression equations varied from between 15% and 1% for the individual component categories of waste, up to 20% for total waste. An alternative set of predicted values of total waste arisings were obtained by summing the predicted values of each of the individual waste components. The correlation of these alternative predicted values with observed values of total waste achieved an improvement in the percentage of explained variance in total waste arisings of 6%, making 26% overall. This result established that, in the case of the principal component model, total waste arisings can be predicted most accurately on the basis of the summation of predictions for the individual waste components.

6.5.9 A truer picture of the performance of the principal components themselves in the role of explanatory variables can be obtained by measuring the explained variance as a proportion of non-random variance as opposed to as a proportion of total variance. In most cases this resulted in a substantial improvement in the measures of the explanatory power of the principal components. For example, the regression analysis explained 15% of the total variance in plastic film but 35% of the non-random variance. Explained variance is given as a proportion of non-random variance for all waste categories in Table 6.7.

6.5.10 The results described above are compared against the performance of conventional methods of waste estimation in section 6.7. It is also instructive to compare the results of the analysis with the results of other research that has used similar statistical techniques. The most notable examples are in the field of market research where principal components analysis have been combined with regression analysis to predict purchasing behaviour. The basis for comparison lies in the fact that 'disposal behaviour' is a corollary of purchasing behaviour (see Chapter 2). Frank et al (1967) conducted separate analyses on the socio-economic correlates of 57 grocery products using regression on principal components. The average coefficient of

Table 6.4 Variables included in the Principle Components Analysis

1. Property Type/Tenure

   Detatched owner occupied
   Private semi-detatched/terraced
   Council semi-detatched/terraced
   Private multi-occupancy flats
   Council maisonettes
   Council multistorey

2. Household Size

   One to Seven plus persons

3. Socioeconomic Group

   A - B Professional/intermediate
   C1 - C2 Skilled non-manual/manual
   D - E Partly skilled/unskilled
   Students/other inactive
   Unemployed
   Retired

4. Family Life Cycle

   Stage 1 Young single
   Stage 2 Young married/no children
   Stage 3 Young married/children
   Stage 4 Older married/children
   Stage 5 Older married/no children
   Stage 6 Older single

   Household Attributes

5. Type of domestic heating

6. Pet ownership

7. Freezer ownership

8. Car ownership

9. Milk delivered

10. Mode of Newspaper Purchase

    None
    Counter sale
    Delivered

Table 6.5 Interpretation of the Six Major Principal Components

Principal Component Number	'Identifier'	Percentage Variance Explained	Variables on which Principal Component Weighting >0.5	
			Variable	Weighting
F1	'Household size'	14.9	FLC6 (older single)	- 0.77
			household size	0.69
			retired	- 0.69
			socioeconomic groups C1, C2	0.57
			Car ownership	
F2	'Young single'	10.00	FLC1 (young single)	0.67
			Private multioccupancy flats	0.50
			Student/other inactive	0.50
F3	'Wealth'	7.8	Detatched onwer-occupied	0.81
			Socioeconomic groups AB	0.68
F4	'Family'	6.7	FLC5 (older couples no children)	- 0.88
			FLC4 (older couples with children)	0.56
F5	'Tenure'	6.1	Council semi-detatched and terraced	- 0.81
			Private semi-detatched and terraced	0.62
F6	'Less Well Off'	6.0	FLC3 (young couples with children)	0.76
			Multistorey Flats	0.61

Table 6.6 Results of the Regression Analysis of Household Waste Arisings Against the Six Major Principal Components

Waste Categories	Form of Regression Equation	R	R^2	Adjusted R^2	Residual Error (kg/hh/wk)
Total Waste	$W = 1.18F_1 - 0.60F_6 + 0.54F_4$	0.45	0.20	0.20	5.81
Kitchen Waste	$W_1 = 0.34F_1 \div 0.06F_4 - 0.06F_2$	0.37	0.14	0.14	2.50
Garden Waste	$W_2 = 0.10F_4 + 0.10F_3 - 0.07F_6$	0.16	0.02	0.02	1.81
Scrap paper etc.	$W_3 = 0.27F_1 + 0.11F_4 + 0.07F_3 - 0.06F_6$	0.34	0.11	0.11	0.70
Newsprint	$W_4 = 0.17F_1 - 0.08F_6$	0.18	0.03	0.03	1.40
Cardboard	$W_5 = 0.31F_1 + 0.11F_4 - 0.06F_5$	0.36	0.13	0.13	0.57
Ferrous	$W_6 = 0.25F_1 + 0.07F_4$	0.28	0.08	0.08	0.59
Non-Ferrous	$W_7 = 0.16F_1$	0.16	0.02	0.02	0.17
Textiles	$W_8 = 0.15F_1$	0.15	0.02	0.02	0.97
Glass	$W_9 = 0.20F_1 + 0.15F_3 + 0.11F_2$	0.28	0.08	0.08	1.25
Plastic Film	$W_{10} = 0.13F_1 + 0.12F_4 + 0.08F_2 + 0.06F_3$	0.38	0.15	0.15	0.22
Dense Plastic	$W_{11} = 0.21F_1$	0.21	0.04	0.04	0.33
Misc. Combustible	$W_{12} = 0.10F_1 + 0.10 F_4$	0.15	0.02	0.02	1.28
Misc. Non-combustible	$W_{13} = 0.08F_4$	0.08	0.01	0.01	0.81
Fines	$W_{14} = 0.11F_1 - 0.06F_6$	0.12	0.01	0.01	1.00

Table 6.7 Variance in Waste Arisings Explained by Principal Components Model Expressed as a Proportion of Non-random Variance

WASTE CATEGORIES	PERCENTAGE OF NON-RANDOM VARIANCE EXPLAINED
Total Waste	31.0
Kitchen Waste	19.2
Garden Waste	3.8
Scrap Paper etc.	13.1
Newsprint	4.5
Carboard	18.5
Ferrous	11.6
Non-Ferrous	-
Textiles	3.2
Glass	11.1
Plastic Film	34.6
Dense Plastic	4.6
Misc. Combustible	11.4
Misc. Non-combustible	2.1
Fines	1.3

determination for the 57 products was 11%*. This compares with an average coefficient of determination of 9% for the categories of household waste.

Cross-Validation and Tests of Inferential Statistics

6.5.11 The 'R^2' measures of goodness of fit given in table 6.6 were tested for their 'stability' (i.e. the degree to which they were generalisable) by the process of split-half cross-validation. This involved splitting the data set randomly into two groups and deriving regression coefficients on the basis of one half of the data set only. Adjusted measures of goodness of fit were then obtained by correlating 'predicted values' of waste arisings, derived on the basis of the regression coefficients, with the 'observed values' in the second half of the data set. The values of the adjusted R^2's are given in Table 6.6. The difference between the adjusted R^2 and the unadjusted R^2 in each case is referred to as 'shrinkage' and is an indication of the stability of the original R^2. The degree of shrinkage associated with each regression equation is very small to the extent that the adjusted and unadjusted R^2's are equal at two decimal places. This is explained by the fact that the regression equations are given stability by the large sample sizes that were used.

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* In a later paper Frank et al (1975) conclude that, although research designs in marketing studies vary considerably, the coefficients of determination obtained are generally similar and seldom exceed 0.20.

6.5.12 The inferential statistics used in the regression analysis are based on assumptions about normality and homoscedasticity (constant variance) in the error term. The consequences of non-normality and heteroscedasticity are that the tests of significance of the regression parameters will be weakened, although the regression coefficients themselves will still be unbiased estimates of the true regression parameters. Frequency distributions of the residual were produced for each category of waste to test for normality of the residual. All were approximately Gaussian in shape. The distribution for total waste is reproduced in Figure 6.7. Heteroscedasticity was tested for by plotting observed values of waste arisings against expected values for each waste category. No systematic pattern in the residual was observed and it was therefore concluded that the regression analysis was not invalidated by heteroscedasticity. The 'observed-expected' plot for total waste is reproduced in Figure 6.8.

6.6 Waste Arisings Model Based on Categories of Household

6.6.1 The second of the two household-based waste arisings models (model type (1)) was based on the 'category model' approach. The advantage of the category model is that it overcomes the restrictive assumption of additivity inherent in the conventional regression analysis approach. Provided that categories of household are defined in such a way as to be identifiable and measurable in practice, the category model also has the advantage over the approach based on principal components that it can be used for the estimation of waste

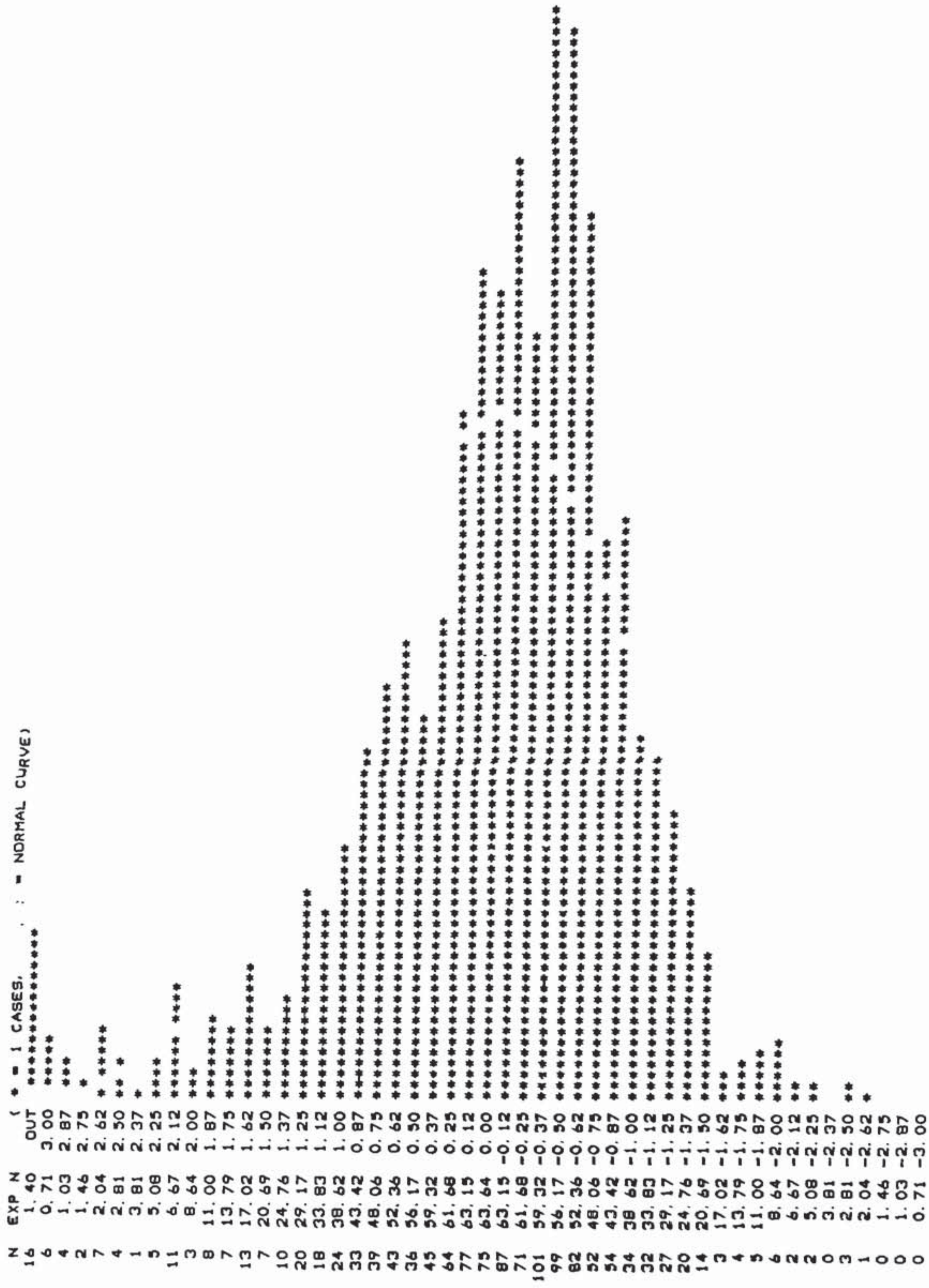

Fig. 6.7 Frequency distribution of standardised residual for total waste arisings

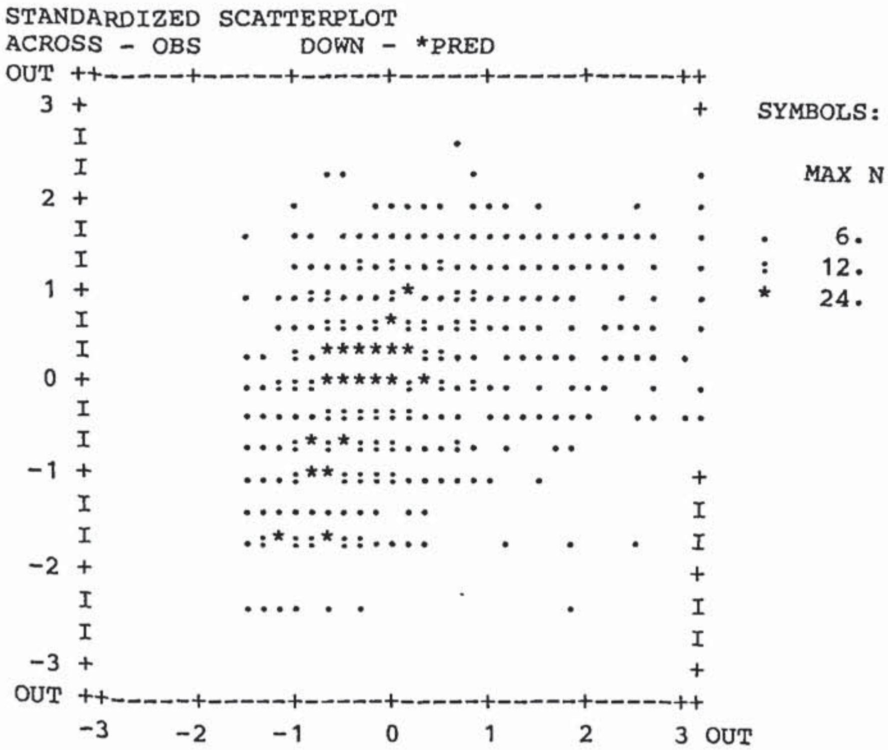

Fig. 6.8 Plot of standardised observed and predicted levels of total waste arisings

arisings in unsurveyed areas. The disadvantages of using a category model in this context derive from the fact that the large number of household characteristics related to waste arisings make it impossible to take account of all of them in the definition of household categories. As a result of the exclusion of certain household characteristics from the analysis the following limitations may result:

(1) Goodness of fit may be diminished.

(2) Bias may be introduced, since the waste coefficients obtained for each household category will reflect both the effects of the variables used to define the category and the hidden, spurious effects of other variables disproportionately represented in the group. However, the robustness of the model will be unaffected as long as the variables taken account of in the model, and those excluded from the model, continue.

Methodology

6.6.2 The first stage in the development of the category model was the selection of household characteristics to provide a basis for the cross-classification of households. The number of variables chosen for this purpose involved making a trade-off between parsimony and goodness of fit. Creating extra categories of household will almost always increase the goodness of fit (although not necessarily significantly) and never reduce it. However the size of the model, in terms of the number of categories of household, will increase rapidly according to the number of variables added. In order to achieve an 'ideal' trade-off between accuracy and parsimony (i.e. the smallest number of categories of household for a given level of accuracy) it would have been necessary to start with all the possible categories of household and systematically combine categories in which the mean waste arisings were closest to one another. The reason that this strategy was rejected was that there were far too many possible categories of household to make this a practicable exercise. In general it was found that where more than four variables were used the number of categories became too large and the programme capacity of the computerised n-way analysis of variance routine used to derive a statistical summary of the model was exceeded.

6.6.3 The variables used to define the categories of household were selected against three criteria:

(1) The strength of the relationships between the variables and waste arisings.

(2) The extent to which the variables were mutually uncorrelated.

(3) The availability of geographically comprehensive estimates of the variables.

Because the modelling exercise was not concerned at this stage with developing an operational method of waste estimation, the third criterion was not permitted to constrain the other two. Variables were evaluated against these criteria on the basis of the results of the principal components analysis and the regression analysis described in the preceding section. The four variables which emerged from this two-stage analysis as those least intercorrelated and simultaneously the most powerful explanatory variables in relation to waste arisings were: household size; Family Life Cycle; occupation of the head of household (2 categories: economically active and economically inactive) and tenure (2 categories: private and council). Cross-classification of these four variables resulted in 144 different categories of household.

Results

6.6.4 The following discussion illustrates the way in which the different categories of household discriminated between different average levels of waste arisings. Clearly, with 15 separate categories of waste divided among 144 different categories of household it would be impracticable to describe in detail the contrast between all household categories for all types of waste. 'Total waste' has therefore been used as an example to illustrate well defined trends and patterns in waste arisings among categories of household.

6.6.5 Tables 6.8 and 6.9 both compare the mean total weight of waste generated by households of between 3 and 6+ persons, and at stages 3 and 4 in the Family Life Cycle. Table 6.8 represents households where the head of household is economically active and Table 6.9 represents households where the head is economically inactive. Both tables refer to households in private dwellings as opposed to council dwellings. The tables highlight the following points:

- there is a clear gradient in the weight of total waste according to household size, increading from households with 3 persons to households with 6+ persons. However, the gradient is much more marked among households at stage 3 in the Family Life Cycle, to the extent that whereas 3 person households at stage 3 in the Life Cycle generate less waste than their counterparts at stage 4 in the Life Cycle, the reverse is true in the case of the 6+ person household group.

- For the combinations of household size, Family Life Cycle and tenure shown, there is little overall difference in the level of total waste arisings between economically active and economically inactive housholds.

6.6.6 Table 6.10 compares households at stages 5 and 6 in the Family Life Cycle. Households at stage 5 in the Life Cycle are, by definition a subset of 2 person households, and similarly households at stage 6 in the Life Cycle are a subset of 1 person households. The table shows that, in all cases, the 'solitary survivors' generate less waste than the older couples with no children living with them. Within this general pattern there are also differences between households grouped according to occupation of household head and tenure. Economically active households generate more waste on average than economically inactive households at stages 5 and 6 in the Family Life Cycle (8.97 kg/hh/wk and 6.97 kg/hh/wk respectively), and households in private dwellings generate more waste on average than households in council dwellings (7.83 kg/hh/wk and 6.86 kg/hh/wk respectively).

6.6.7 Table 6.11 illustrates the way in which the weight of total waste varies across <u>all stages in the Family Life Cycle</u> among groups of households with 3 and 4 persons in the economically inactive/private tenure bracket. Among households with 3 persons, the largest quantities of waste are generated at stage 1 in the Family Life Cycle, with households at stage 3 in the Life Cycle generating slightly less waste than households at stage 4. Among 4-person households the differential between stages 3 and 4 is maintained but households at stage 4 now generate more waste than households at stage 1. This pattern is consistent with the fact that 3-person households will in general consist entirely of adults in stage 1 but of two adults and one young child (with lower nutritional requirements) in stages 3 and 4. The composition of 4 person households, however, will be different. At stage 4 in the Life Cycle the usual composition of 4 person households will be 2 adults and 2 adolescent children and the overall nutritional demand will be equal to that of the all-adult households at stage 1 in the Life Cycle. Super-imposed on this pattern is a marked difference in the average level of total waste arisings between 3 and 4 person households.

6.6.8 Tables 6.12 and 6.13 illustrate the differences in waste arisings between households of the same size but at divergent points in the Family Life Cycle. Table 6.13 contrasts households containing young couples (no children living with them) with households containing older couples (no children living with them). Table 6.13 contrasts young single people living alone with solitary survivors. The groups are split according to occupation of household head into economically active and economically inactive groups. All figures refer to households in private dwellings. The tables show that young people living alone generate more waste on average than 'solitary survivors' and that young couples generate more waste on average than their older counterparts. In all cases these differences are more marked among the economically active groups than among the economically inactive groups.

6.6.9 The above discussion has illustrated the substantial differences in waste arisings that occur between households grouped into categories according to selected household characteristics. The overall goodness of fit of the category model can be measured in terms of the multiple correlation coefficient 'R' and the coefficient of determination 'R^2'.

Tables 6.8/6.9 Variation in Total Waste Arisings (kg/hh/wk) Between Selected Categories of Private Tenure Households

Table 6.8

HEAD OF HOUSEHOLD ECONOMICALLY ACTIVE		
Household Size	Stage in Family Life Cycle	
	Stage 3	Stage 4
3 Persons	9.24 (43)	10.66 (34)
4 Persons	13.03 (56)	11.44 (59)
5 Persons	13.09 (19)	14.18 (48)
6+ Persons	22.24 (6)	16.63 (27)

Table 6.9

HEAD OF HOUSEHOLD ECONOMICALLY INACTIVE		
Household Size	Stage in Family Life Cycle	
	Stage 3	Stage 4
3 Persons	9.00 (5)	9.67 (8)
4 Persons	10.10 (9)	13.52 (11)
5 Persons	15.97 (3)	13.01 (5)
6+ Persons	24.30 (2)	17.60 (2)

(Numbers in brackets refer to size of sample)

Table 6.10 Variation in Total Waste Arisings (kg/hh/wk) between Categories of Household at Stages 5 and 6 in the Family Life Cycle

Tenure	Occupation of Household head	Stage in Family Life Cycle	
		Stage 5	Stage 6
Private	Economically Active	9.38 (87)	5.11 (14)
	Economically Inactive	8.21 (159)	5.87 (100)
Council	Economically Active	8.76 (35)	7.37 (8)
	Economically Inactive	7.04 (76)	5.35 (56)

(Numbers in brackets refer to size of sample)

Table 6.11 Variation in Total Wase Arisings (kg/hh/wk) between Selected Categories of Economically Inactive Households in Private Dwellings

Household Size	Stage in Family Life Cycle					
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
3 Persons	11.29 (9)	0.00 (0)	9.00 (5)	9.67 (8)	0.00 (0)	0.00 (0)
4 Persons	11.90 (4)	0.00 (0)	10.10 (9)	13.52 (11)	0.00 (0)	0.00 (0)

(Numbers in brackets refer to size of sample)

Table 6.12/6.13 <u>Variation in Total Waste Arisings (kg/hh/wk) Between Categories of Household with 1 Person and 2 Persons in Private Dwellings</u>

Table 6.12

ONE PERSON HOUSEHOLDS		
Occupation of Household Head	Stage in Family Life Cycle	
	Stage 1	Stage 6
Economically Active	5.46 (8)	5.11 (14)
Economically Inactive	6.65 (4)	5.87 (100)

Table 6.13

TWO PERSON HOUSEHOLDS		
Occupation of Household Head	Stage in Family Life Cycle	
	Stage 1	Stage 6
Economically Active	10.80 (38)	9.83 (87)
Economically Inactive	12.44 (8)	8.21 (159)

(Numbers in brackets refer to size of sample)

These statistics are directly comparable with the corresponding statistics used to describe the principal components model, and can be used to compare the performances of the two different approaches. Table 6.14 shows that in terms of goodness of fit the category model is slightly better overall than the model based on principal components. This result is somewhat surprising since the principal components model incorporated a more comprehensive set of household characteristics than the category model. One possible explanation is the loss of information which occurred at the stage of selection of the major principal components used in the regression analysis.

6.7 Comparison of the Performance of Principal Components and Category Models with Existing Methods of Waste Estimation

6.7.1 The decisive test of the advances made by the two types of household waste model described in this chapter is the way in which they compare with existing methods of waste estimation. A partial evaluation of existing methods of waste estimation has already been made in Chapter 1, section 1.3. The evaluation was made on a priori basis against criteria which included the appropriateness of the levels of spatial aggregation and the units of waste categorisation and measurement associated with each method. This section compares the newly developed and existing methods on an empirical basis in terms of their accuracy and the proportion of variance in household waste arisings which they are able to explain. A complete summary and evaluation of the models developed in this research against current practice is given in Chapter 9, section 9.2.3.

6.7.2 In order to provide a basis for comparison the two methods of waste estimation which are in current use in the UK (the 'per capita' method and the 'Higginson' method) were tested on the data set containing information on the 1277 households. The performance of the per capita method was measured in terms of 'kilogrammes per household per week' by first dividing the measurements of each category of waste for each individual household by the household size. The standard deviations of the resulting 'per capita' values were then multiplied by the overall mean size of household to give a 'household equivalent' estimate of error for each category of waste. Estimates of the error associated with the 'Higginson method' were obtained by grouping households in the data set according to five categories of dwelling: detatched owner-occupied; private semi-detatched and terraced; council semi-detatched and terraced; private flats and council flats. The proportions of variance in each category of waste explained by this grouping were then measured. The use of five categories to classify households represents a generous interpretation of the Higginson method, since the DoE recommended version of Higginson makes provisions for only 3 categories of household.

6.7.3 Table 6.15 compares the performances of the principal components and category models with the performance of the per capita and Higginson methods. Performance is measured in terms of the mean error of estimate of a single week's waste from a single household, and in terms of the percentage of variance in household waste arisings explained by each method. The main points highlighted by the table are summarised below:

- The highest levels of error are associated with the traditional 'per capita' method. The average weight of weekly waste arising per household is clearly a better estimator than the average per capita weight of waste. This fact confirms the underlying premise of the research that the household and not the individual is the fundamental unit of waste generation.

- The 'Higginson method' represents a distinct improvement over the per capita method, but explains only a small fraction (up to 5%) of the total variation in individual household weekly waste arisings.

- Both types of household-based model developed in this research proved substantially better at estimating waste arisings than existing methods in current use. On average, the new methods explained five times as much variance in household waste arisings as the next best 'rival' - the Higginson method.

Table 6.14 Comparison of the Performances of the Principal Components and Category Models in Terms of the Multiple Correlation Coefficient (R) and the Coefficient of Determination (R^2)

WASTE CATEGORIES	PRINCIPLE COMPONENTS MODEL		CATEGORY MODEL	
	R	R^2	R	R^2
Total Waste	0.51	0.26	0.48	0.23
Kitchen Waste	0.37	0.14	0.43	0.18
Garden Waste	0.16	0.02	0.16	0.03
Scrap Paper etc.	0.34	0.11	0.37	0.13
Newsprint	0.18	0.03	0.17	0.03
Cardboard	0.36	0.13	0.37	0.14
Ferrous	0.28	0.08	0.31	0.10
Non-Ferrous	0.16	0.02	0.17	0.03
Textiles	0.15	0.02	0.18	0.03
Glass	0.28	0.08	0.26	0.07
Plastic Film	0.38	0.15	0.40	0.16
Dense Plastic	0.21	0.04	0.22	0.05
Misc. Combustible	0.15	0.02	0.25	0.06
Misc. Non-Combustible	0.08	0.01	0.14	0.02
Fines	0.12	0.01	0.21	0.05
Mean	0.25	0.08	0.27	0.09

Table 6.15 Comparison of the Principal Components and Category Model with Existing Methods of Waste Estimation

Method of Waste Estimation / Measure of Performance / Waste Categories	Mean Waste per household per week		'Per capita' Method		Higginson Method		Principal Components Model		Category Model	
	Standard Deviation (kg/hh/wk)	Percentage Variance Explained	Error of Estimate (kg/hh/wk)	Percentage Variance Explained	Error of Estimate (kg/hh/wk)	Percentage Variance Explained	Error of Estimate (kg/hh/wk)	Percentage Variance Explained	Error of Estimate (kg/hh/wk)	Percentage Variance Explained
Total Waste	6.48	00.0	8.00	00.0	6.32	5.3	5.49	26.0	5.56	22.2
Kitchen Waste	2.69	00.0	3.23	00.0	2.67	2.3	2.50	14.1	2.39	17.2
Garden Waste	1.84	00.0	2.69	00.0	1.82	2.0	1.81	2.4	1.73	2.5
Scrap Paper etc.	0.74	00.0	0.75	00.0	0.73	2.7	0.70	11.5	0.63	13.4
Newsprint	1.42	00.0	1.80	00.0	1.41	2.1	1.40	3.1	1.40	2.7
Cardboard	0.61	00.0	0.58	00.0	0.60	1.6	0.57	13.0	0.57	13.9
Ferrous	0.61	00.0	0.83	00.0	0.61	1.2	0.59	7.9	0.54	9.7
Non-Ferrous	0.17	00.0	0.19	00.0	0.17	0.5	0.17	2.5	0.17	3.0
Textiles	0.98	00.0	0.94	00.0	0.98	0.3	0.97	2.4	1.00	3.4
Glass	1.30	00.0	1.58	00.0	1.28	3.3	1.25	7.9	1.18	6.5
Plastic Film	0.24	00.0	0.29	00.0	0.23	1.7	0.22	14.8	0.22	16.2
Dense Plastic	0.34	00.0	0.43	00.0	0.34	0.5	0.33	4.3	0.33	4.6
Misc. Combustible	1.29	00.0	1.77	00.0	1.29	0.4	1.28	2.4	1.21	6.1
Misc. Non-combustible	0.82	00.0	1.34	00.0	0.82	0.6	0.82	0.7	0.76	1.9
Fines	1.01	00.0	1.36	00.0	1.01	0.5	1.00	1.4	0.99	4.5

Conclusions

6.7.4 This chapter has established a number of important points both in relation to the hypotheses of this research and in relation to the potential scope and usefulness of the behavioural approach to waste modelling:

(1) Empirical testing confirmed the majority of the research hypotheses developed in Chapter 2 relating the characteristics of households to the process of waste generation. All twenty of the household characteristics tested were found to be significantly associated with at least one category of waste.

(2) By considering household characteristics jointly in the form of statistical models it was possible to explain up to 26% of the total variation in individual household weekly waste arisings. This represents a substantial improvement over conventional methods of waste estimation which were found to explain at best only 5% of the total variation in waste arisings.

(3) Comparison of the error associated with the per capita method with the error associated with the average waste per household confirmed the initial premise of the research that the household and not the individual is the basic unit of waste generation.

(4) The substantial and systematic differences which were found between households grouped according to four measurable characteristics highlights the potential strength and usefulness of the method in the practical context of waste estimation. This aspect of the research is developed further in the following chapter, Chapter 7.

CHAPTER SEVEN

DEVELOPMENT OF AN AREA-BASED WASTE ARISINGS MODEL

7.1 Introduction and Aims

7.1.1 This chapter describes the transformation of the household based model described in the previous chapter into an area-based prediction model. The development of a method to obtain area estimates of waste arisings responds to the fourth and final objective of the research, namely "to develop an area-based model to obtain household waste information in a form which is appropriate to the practical needs of waste management."

7.1.2 The chapter is organised in three main sections. Section 7.2 compares the possible alternative approaches to the area estimation of waste arisings and explains the rationale for the methodology used. Section 7.3 describes the calibration of the area-based model and how in practice the model was applied to two case study areas. Section 7.4 discusses the results of the two cases studies, firstly from the perspective of the type and magnitude of differences in waste arisings that exist between areas, and secondly from the perspective of the usefulness of the model in practical waste management contexts. An overall appraisal of the findings of the chapter is given in the concluding section.

7.2 Alternative Approaches to the Area Estimation of Waste Arisings

7.2.1 There are several possible alternative approaches to the area estimation of waste arisings. These are summarised diagramatically in Figure 7.1. Each approach is critically discussed below:

(1) The first approach involves the development of a regression type model based on area data. This involves determining the relationship between aggregate or average measures of waste arisings and corresponding aggregate or average *measures of explanatory variables*. For example, such a model may attempt to estimate the waste arisings from a particular area on the basis of area data on a set of separate socio-economic or demographic variables. This approach has been adopted in a number of part studies of waste arisings (e.g. Richardson and Havlicek 1974, Grossman 1974) which have been discussed in Chapter 1. Implicit in the use of regression analysis is the assumption that the explanatory variables are independent of one another in their effect on waste arisings. However, the analysis of the household waste survey results in Chapter 6 has established that interaction exists between the main waste-related explantory variables. The regression approach is therefore unsuitable in this context.

(2) The second possible approach to the area estimation of waste arisings is to classify areas into types on

Figure 7.1 Taxonomy of Alternative Approaches to the Area Estimation of Waste Arisings

Estimation of the quantity and composition of household waste within a given area

- Multiple regression to determine the relationship between waste arisings and aggregate or average measures of area characteristics
- Classification of areas on the basis of area characteristics and sampling to estimate waste arisings generated by each area type
- Identification of number of households of predefined types within area and multiplication by household waste generation coefficients

the basis of selected area characteristics and to derive, by refuse sampling and measurement, 'area waste coefficients' for each area type. This approach has recently been advocated by Davies (1983). The advantage of a system of area classification is that it reduces spatial complexity and potentially allows clear geographical patterns in waste arisings to be identified. However there are also a number of problems associated with the approach:

(a) The first problem is that there may be systematic differences in waste arisings between two ostensibly identical areas. This is because two areas with the same aggregate scores on a set of household variables may contain entirely different types of households. Unless the aggregate household scores can be disaggregated to take account of the way in which the variables combine at the individual household level then nothing can be inferred about the characteristics of individual households within the area (to make inferences about the way in which variables combine at the household level from the way in which they combine at the area level is to commit the notorious 'ecological fallacy' identified by Robinson 1950). The use of this approach therefore makes the assumption that areas which are similar at an aggregate level are homogeneous in terms of the households which they contain. As a result important differences in waste arisings between areas may be submerged and the area waste coefficients may be unreliable.

(b) The second problem with the area typology approach is that to classify areas on a geographically comprehensive basis involves extensive data analysis (Goosmann 1980). This problem could potentially be overcomme by grafting the method on to an existing system of area classification (such as that described by Webber (1977)). However the result is likely to be coarse and insensitive to variations in waste arisings since existing systems of area classification are based on sets of classificatory variables which include many variables that are unrelated to waste arisings.

(c) The third problem with the area classification approach is that there is no body of retrospective data available to indicate the way in which area-types are expanding or contracting in size, and therefore no basis exists for the forecasting of waste arisings using this method.

(3) The third alternative approach to the area estimation of waste arisings involves identifying the number of households of different types within a particular area and simply adding together the estimated waste arisings from each group of households using individual household waste coefficients. The advantage of this

approach is that it maintains the individual household as the fundamental unit of prediction and is therefore founded on a sound theoretical footing. No information is lost in the process of transferring the model from the household to the area level. In terms of the criteria of validity and reliability this approach is therefore the most satisfactory of the three. However, the usefulness of the method in practical terms depends on the extent to which it is possible to characterise an area in terms of the household types which it contains, where 'household types' are defined in such a way so as to reflect fully the variation in waste arisings. In the past, though survey information on households has been available, the fact that it has not been geographically comprehensive or easily handled has made it difficult or costly to obtain detailed household profiles for small areas. Recently however there has been an expansion in the amount of household information held on computer databases which has meant that detailed breakdowns of the types of households within any predefined area can be accessed directly and used as a basis for further analysis. It was therefore this third type of approach to area waste estimation that was pursued in the research, as described in detail in section 7.3.

Potential Sources of Household Information

7.2.2 In order to operationalise the method of area estimation of waste arisings described above it was necessary to identify a suitable database containing information on the appropriate explanatory variables at the appropriate disaggregate level. A number of alternative sources of data were received. These are summarised in Table 7.1. Of the alternatives described, census data was chosen because, in addition to providing information on relevant household characteristics, it also satisfied criteria relating to practical waste management needs. These criteria have been set out in section 1.2.6 of Chapter 1 and are also reiterated in section 7.4.1 of this chapter:

(1) Functions at the Appropriate Level of Aggregation

The smallest spatial area for which census information on individual households is available is the enumeration district (ED). This is the area covered by one census enumerator and typically contains about 400-500 people or about 150-200 households. The smallest area of practical interest in waste management contexts is the waste collection round (see Chapter 3, section 3.3). On a typical trip a dustcart will collect from 300-800 households, equivalent to the combined area of between 2 and 4 enumeration districts. In addition, enumeration districts can easily be assembled into larger zones corresponding to larger areas of interest

Table 7.1 Review of Alternative Sources of Area Data on Household Characteristics

KEY	NAME OF SURVEY	HOUSEHOLD CHARACTERISTICS
Census	1981 national census	(1) household size (2) occupation of household head (3) tenure (4) property type (5) car ownership (6) frequency of shopping trips for food (7) age of household head (8) number of bedrooms (9) freezer ownership
WMHS	West Midlands Household Survey (1976)	
FES	Family Expenditure Survey (annual)	
GHS	General Household Survey (annual)	

SURVEY	FORM OF DATA	LEVEL OF RESOLUTION	SAMPLE SIZE	REMARKS
Census	(1) (3) (5) (1 x 2) (1 x 3) (2 x 3)	ED	100%	See para 7.2.2
WMHS	(1) (3) (4) (5) (1 x 3) (1 x 4) (2 x 4) (2 x 6) (3 x 4) (3 x 8) (4 x 8) (5 x 6) (6 x 9)	Varies from ED to Ward Level	5%	1. Data an appropriate household characteristics are not available at the required level of resolution. 2. The survey is not retrospective or regularly updated. 3. The survey is not geographically comprehensive and is based on a small sample.
FES	(1) (2) (3) (2 x 3)	Regional National	1276 7000	1. The levels of resolution are too low to be of operational value
GHS	(1 x7) (2 x 7)	National	11406	2. The sample sizes are proportionally very small.

such as the catchments of disposal facilities or the administrative areas of waste disposal authorities.

(2) Geographically Comprehensive, Regularly Updated and Retrospective

Census Small Area Statistics (SAS) are available for each of the 112,030 enumeration districts in England and Wales. The census is updated every ten years and projections of census variables can be obtained from Central Statistical Office sources to provide a basis for waste forecasting (see Chapter 8).

(3) Readily Accessible

The census small area statistics can be readily accessed through computers linked to any one of five regional computer centres throughout the country. All local authorities and Universities have free and direct access to the census information for research purposes.

7.2.3 Summarising this section, the approach selected for the development of an area prediction model was based on the summation of estimated waste arisings from individual households within an area. This approach was chosen as a result of the careful evaluation of the various possible options. The national census provides information on the appropriate socio-economic and demographic characteristics of households at an appropriate level of aggregation and in a readily accessible form.

7.3 Calibration of the Model and Practical Operation of the Model

7.3.1 The core of the area based model developed in this research was a modified version of the category-type household prediction model developed in Chapter 6. The essential difference between the two was that whereas the household category model was based on four household characteristics the area model was built on three, namely household size, tenure and occupation of household head. These variables were chosen because they had been found to be closely related to the generation of household waste (see Chapter 6) and because by cross-classification they jointly defined 24 categories of household on which information was available from the national census. The 'goodness of fit' of the category model at the household level is discussed in paragraph 7.3.3. Household 'waste generation coefficients' were derived for each of the 24 categories of household on the basis of the results of the field survey of 1277 households.

7.3.2 By combining census information with the series of waste generation coefficients it became possilbe to obtain area estimates of waste arisings by the following procedure:

(a) Taking the average waste arisings (waste generation coefficients) for each household type.

(b) Multiplying by the numbers of each household type present in the census area.

(c) Adding up the results to obtain the total quantity and composition of household waste generated within the census area.

The model can be expressed in mathematical form in the following way:

$$W = \sum_{i,j,k} n_{ijk} \cdot (W_{ijk})$$

where i = household size
(i = 1 for one person households,
i = 2 for two person households etc)

and j = household tenure
(j = 1 for private dwellings,
j = 2 for council dwellings)

and k = occupation of household head
(k = 1 for economically active,
k = 2 for economically inactive)

and (W_{ijk}) is the waste generation coefficient consisting of the average weight of waste component l generated by household type i, j, k.

and n is the number of households of type i, j, k within a predefined area.

and W_1 is the total weight of waste component 1 generated by all households withing the predefined area.

7.3.3 Tables 7.2 and 7.3 illustrate the substantial differences in waste arisings which exist between the 24 categories of household which form the basis of the area model. The overall 'goodness of fit' of the three-way classification to the field survey data is summarised in Table 7.4. The sacrifice in terms of goodness of fit as a result of using three variables to define categories of household (as opposed to the four variables on which the category model described in Chapter 6 was based) was a relatively small loss of 3% in the explained variance in total waste arisings and a 1% loss on average of explained variance in the individual waste components.

7.3.4 Having described the form and calibration of the area based model, the next step is to explain the procedure for applying the model in practice. This is done fully in the following paragraphs using two case study zones in the West Midlands to demonstrate the method.

Description of Practical Methodology

7.3.5 Two case study zones of contrasting size were chosen in order to illustrate the flexibility of the area prediction model. The first case study zones was the Birmingham Metropolitan Borough with a population of 357,000 households. Within the area there are 30 waste handling and disposal

Table 7.2 Comparison of Average Levels of Total Waste Arisings among Different Categories of Household (kg/hh/wk)

2 PERSONS				5 PERSONS			
8.72				13.51			
Private		Council		Private		Council	
9.25		7.48		13.96		12.28	
EA*	EIA*	EA*	EIA*	EA*	EIA*	EA*	EIA*
10.10	8.64	8.36	7.13	10.10	8.64	8.36	7.13

Table 7.3 Comparison of Average Levels of Kitchen Waste Among Different Categories of household (% weight)

2 PERSONS				3 PERSONS			
31.1				31.3			
Private		Council		Private		Council	
28.7		36.5		30.0		34.5	
EA*	EIA*	EA*	EIA*	EA*	EIA*	EA*	EIA*
30.3	27.6	39.2	35.4	30.0	29.9	36.5	32.0

* EA = Economically active
* EIA = Economically inactive

Table 7.4 Goodness of fit of the three-way classification of households used as a basis for the area estimation of waste arisings

	Multiple Correlation Coefficient R	Coefficient of Determination R^2
Total Waste	0.45	0.20
Kitchen Waste	0.40	0.15
Garden Waste	0.11	0.01
Scrap Paper etc	0.36	0.13
Newsprint	0.18	0.03
Cardboard	0.38	0.14
Ferrous	0.28	0.08
Non-Ferrous	0.16	0.03
Textiles	0.17	0.03
Glass	0.25	0.06
Plastic Film	0.39	0.15
Dense Plastic	0.22	0.05
Misc. Combustible	0.20	0.04
Misc. Non-Combustible	0.10	0.01
Fines	0.12	0.02

facilities (14 of them County Council operated) together with 6 collection depots as shown in Figure 7.2. Estimates of waste arisings were derived for the whole of the Birmingham area. The second case study zone was the Erdington electoral ward which lies within the north east sector of Birmingham as shown in Figure 7.3. The area contains 72 separate enumeration districts for which estimates of waste arisings were individually derived. Household waste generated within Erdington is currently disposed off at Perry Barr incinerator. However, a new Refuse Derived Fuel plant is under construction on the site of the closed-down Castle Bromwich incinerator, and Erdington ward will fall within the catchment area of the new plant when it becomes operational in April 1985. The quantity and composition of Erdington's waste are therefore of special interest.

7.3.6 The 1981 census small area statistics are held on computer filestore at regional computer centres. The small area statistics consist of a series of two dimensional tables, each table representing a cross-classfication of two census variables. The frequencies of households or individual members of the population within the cells of each table are recorded for every enumeration district in England and Wales.

7.3.7 The required census data was retrieved for each of the case study zones by creating programme files and submitting them by computer link to the regional computer centre in

Manchester. The programme commands were based on a computer package called SASPAC which is designed specifically for the purpose of producing tabulations and analyses of census data. The SASPAC programmes contained two types of command:

(1) Commands specifying the areas for which census data was required.

(2) Commands specifying the appropriate 'cells' in the SAS tables containing household information relevant to the estimation of waste arisings.

The census data retrieved by SASPAC was input directly into an SPSS (Statistical Package for the Social Sciences) routine. This second phase of data manipulation had five separate functions:

(1) To combine three 2-way cross-classifications obtained from the census (i.e. household size x tenure, tenure x occupation of household head and household size x occupation of household head) into a single 3-way cross-classification (household size x tenure x occupation of household head).

(2) To multiply the number of households in each of the 24 categories of household defined by the 3-way cross-classification by the appropriate waste generation coefficients for each category of waste.

(3) To sum the total waste arisings associated with each group of households across all 24 household categories to produce an area estimate of waste arisings.

(4) To derive an estimate of error for the area estimates of each category of waste.

(5) Where appropriate, to sum the area estimates of waste arisings from individual enumeration districts across a larger composite area.

An illustrated flowchart of the procedure is given in Figure 7.4. The results in relation to each of the case study zones are discussed fully in section 7.4.

7.3.8 The method described above is potentially highly flexible. It can be applied to any predefined administrative or ad hoc area based on the 'building blocks' of enumeration districts. For example, estimates of waste arisings could be obtained for a circular area of given centre and radius, an irregular area defined by a set of grid references or a specified residential or postal area. Selection of areas may be made conditional on one or more waste characteristics of an area. For example, 'select all areas with more than 30% combustible waste but not more than 30% vegetable or putrescible waste'. The method may potentially be interfaced with a suitable mapping package such as 'GIMMS' in order to produce maps or isoline charts depicting waste arisngs.

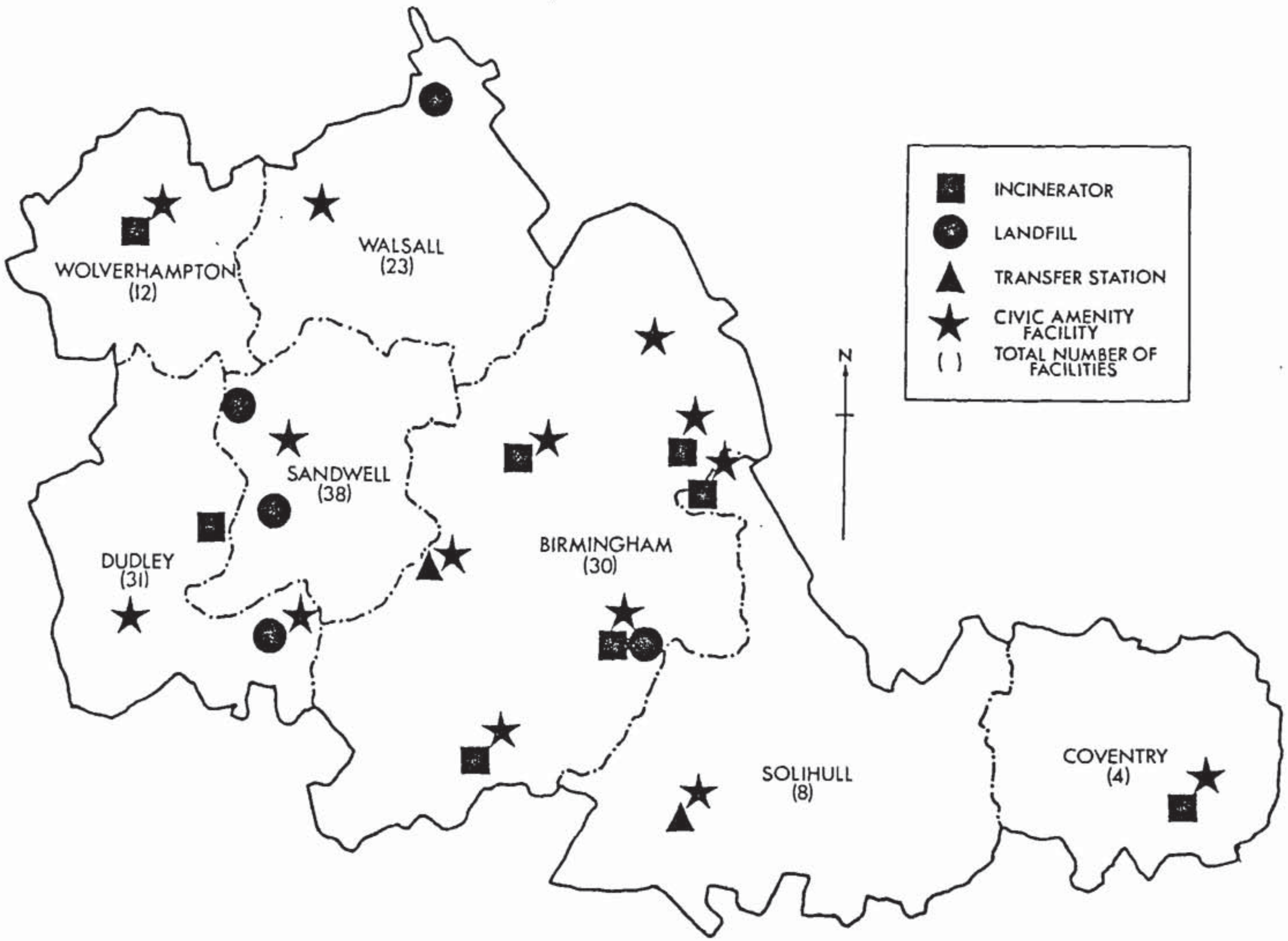

Fig. 7.2 Location of County Council waste disposal facilities and numbers of all types of facility in each district

Fig. 7.3 Map of Birmingham Metropolitan Borough showing the location of Erdington ward

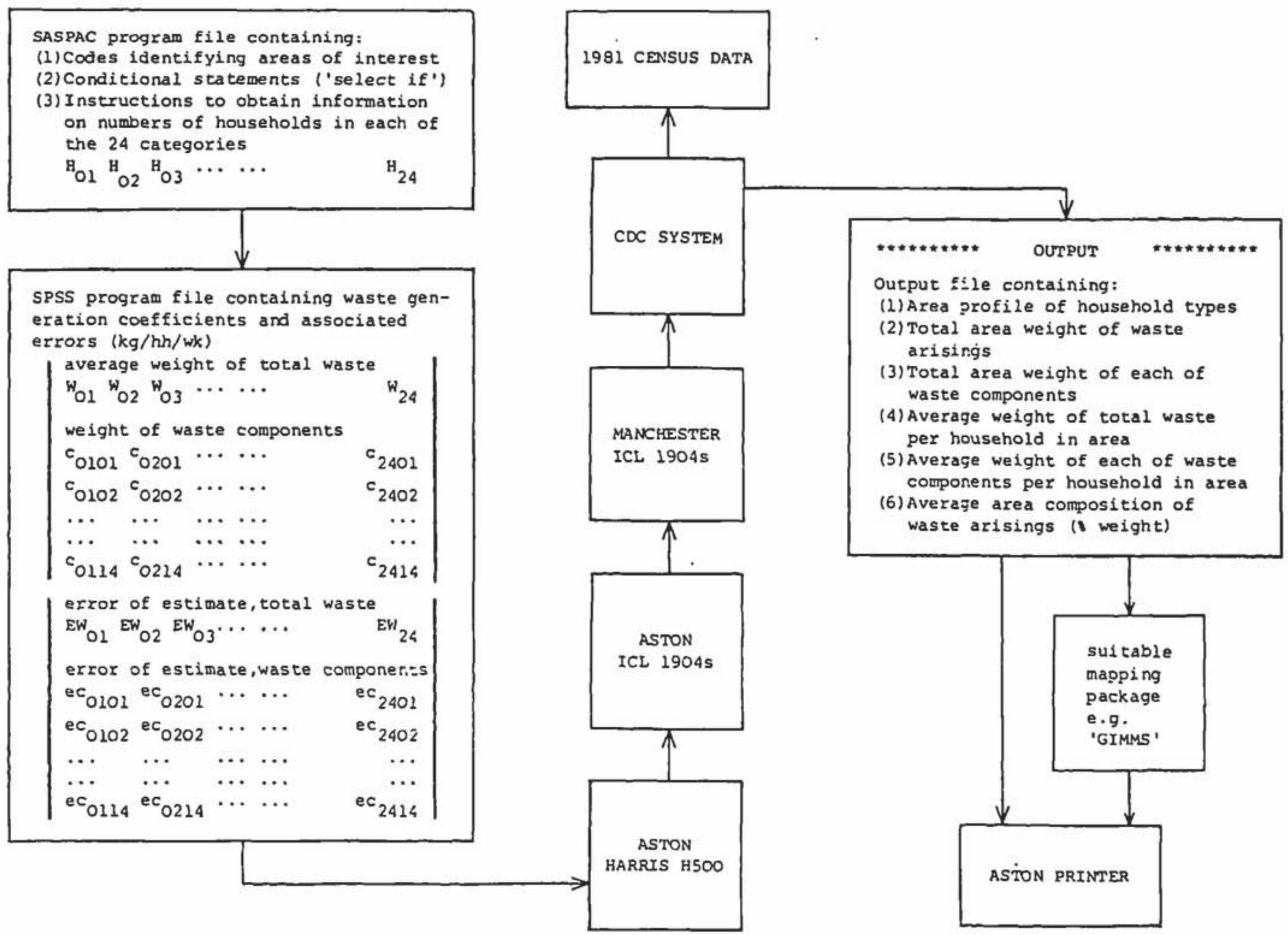

Fig. 7.4 Illustrative flowchart showing method for obtaining area estimates of waste arisings

7.4 Results of the Area Modelling Exercise

7.4.1 This section discusses the results of the area-based waste modelling exercise for the two case study zones. The results are of interest in two respects:

(1) *Firstly as an investigation of the variation in waste* arisings at the area level. Chapter 5 of this thesis established that substantial differences exist in waste arisings between individual households, but depending on the way in which households are distributed spatially, it may or may not be the case that there will be corresponding geographical differences in waste arisings.

(2) The results are also of interest in the context of the development of the area prediction model and evaluating the performance of the model against criteria relating to practical waste management needs. These criteria were originally set out in Chapter 1, section 1.2.6 but are reiterated below for reference:

(a) The method should be simple and cheap to apply and use readily available data.

(b) The method should be capable of estimating the quantity and composition of both present and future household waste arisings.

(c) The method should be applicable at a range of spatial scales to correspond to the diverse aspects of waste management.

(d) The method should be sufficiently sensitive to variations in waste characteristics to measure the effects of alternative decisions in waste management.

(e) The method should be valid, reliable and robust.

The results of the area modelling exercise are discussed from each of the above perspectives in turn.

7.4.2 Table 7.5 and the accompanying Figures 7.5 and 7.6 show for two randomly selected Enumeration Districts within Erdington ward, the predicted quantity and composition of waste arisings together with the profiles of household types within each ED. The two examples illustrate the contrasts between different areas in the balance of household types and the consequences of those contrasts for the quantity and composition of household waste generated. In order to investigate further the variation in area waste arisings between areas, frequency distributions were constructed showing the mean levels of total waste arisings for all Enumeration Districts in Erdington ward. Similar frequency distributions were also constructed for two waste components, kitchen waste and glass, expressed firstly in terms of

Table 7.5 Comparison of Predicted Waste Arisings from Two Randomly Selected Enumeration Districts in Erdington Ward

WASTE CATEGORY	MEAN WEIGHT OF WASTE PER HOUSEHOLD kg/hh/wk		PERCENTAGE WEIGHT		TOTAL WEIGHT OF WASTE IN ED kg/hh/wk (p 0.05)	
	A	B	A	B	A	B
Total Waste	7.54	10.02	100.0	100.0	1576 ± 197	2285 ± 195
Kitchen Waste	2.58	3.24	34.3	32.4	539 ± 63	739 ± 70
Garden Waste	0.54	0.51	7.1	5.1	113 ± 39	116 ± 45
Scrap Paper etc	0.49	0.71	6.5	7.1	102 ± 14	162 ± 19
Newsprint	0.97	1.16	12.9	11.6	203 ± 28	264 ± 38
Cardboard	0.40	0.63	5.3	6.3	84 ± 13	144 ± 23
Ferrous	0.45	0.64	5.9	6.4	94 ± 14	146 ± 17
Non-Ferrous	0.05	0.08	0.7	0.8	10 ± 5	18 ± 7
Textiles	0.21	0.34	2.8	3.4	44 ± 20	78 ± 28
Glass	0.61	0.91	8.1	9.1	127 ± 24	207 ± 31
Plastic Film	0.19	0.27	2.6	2.7	40 ±	
Dense Plastic	0.16	0.24	2.2	2.4	33 ± 8	55 ± 11
Misc. Combustible	0.41	0.59	5.5	6.0	86 ± 27	135 ± 37
Misc. non-combustible	0.13	0.22	1.7	2.2	27 ± 15	50 ± 21
Fines 2cm	0.35	0.48	4.7	4.8	73 ± 45	109 ± 36

KEY

	ED CODE	NUMBER OF HOUSEHOLDS
'A'	CNAJ42	209
'B'	CNAJ65	228

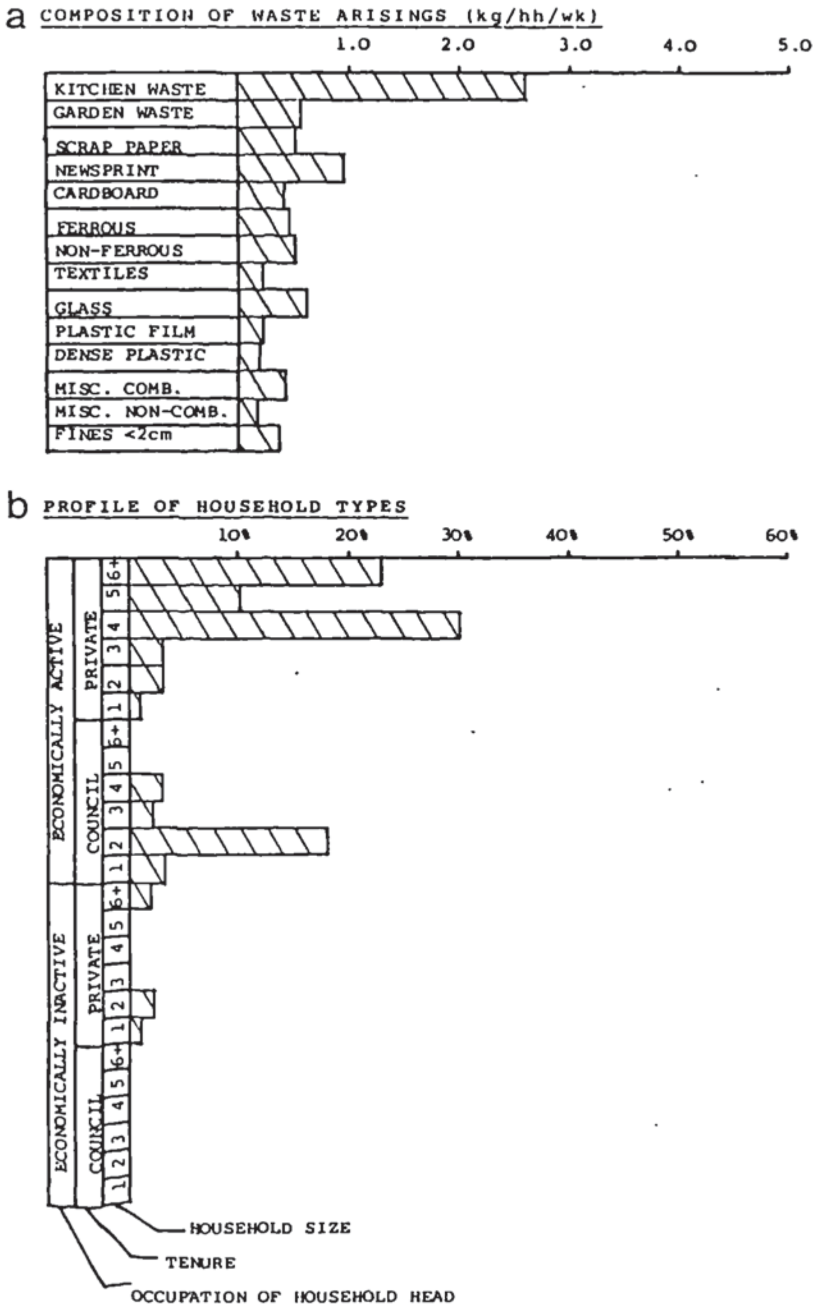

Fig. 7.5 Profiles of (a)waste composition and (b)household types for selected Enumeration District 'A' (E.D.: CNAJ42)

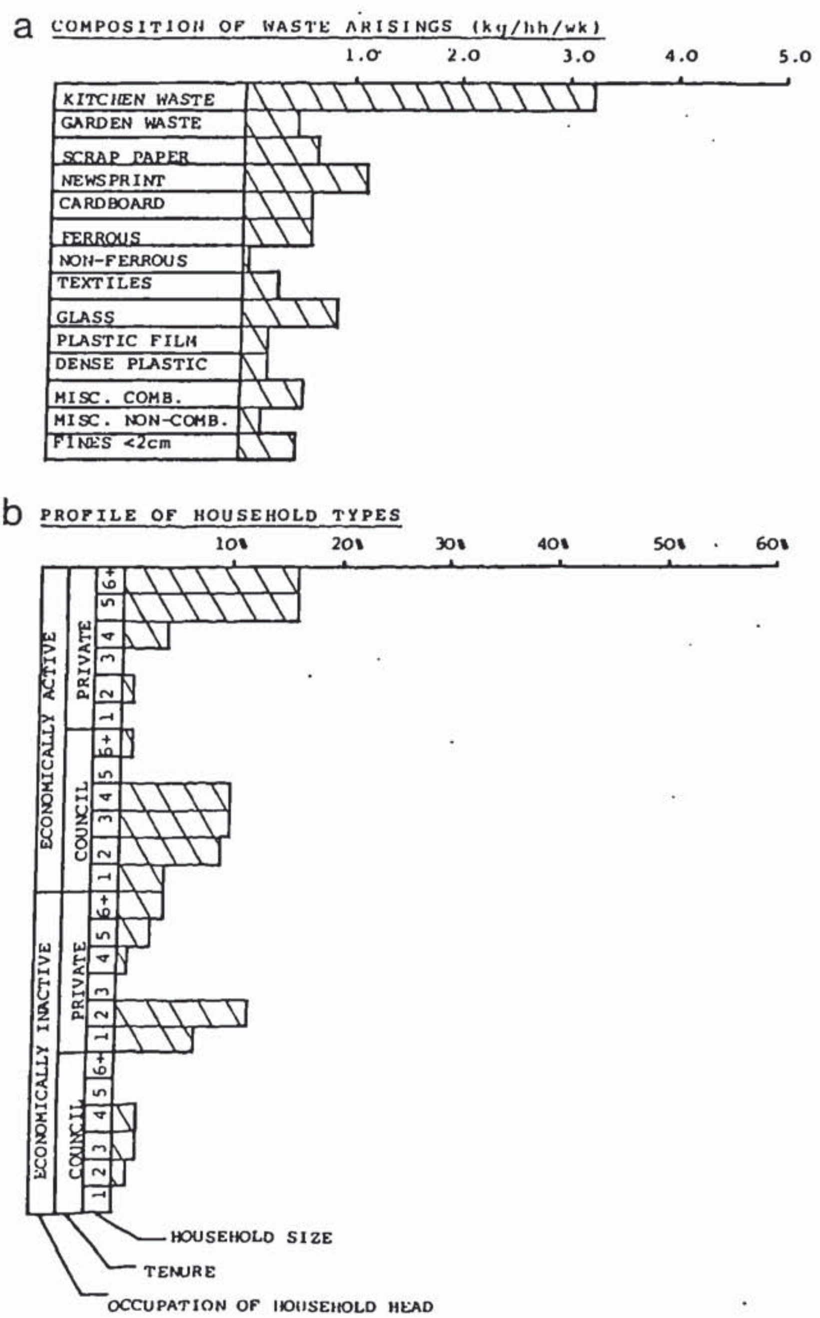

Fig. 7.6 Profiles of (a) waste composition and (b) household types for selected Enumeration District 'B' (E.D.: CNAJ65)

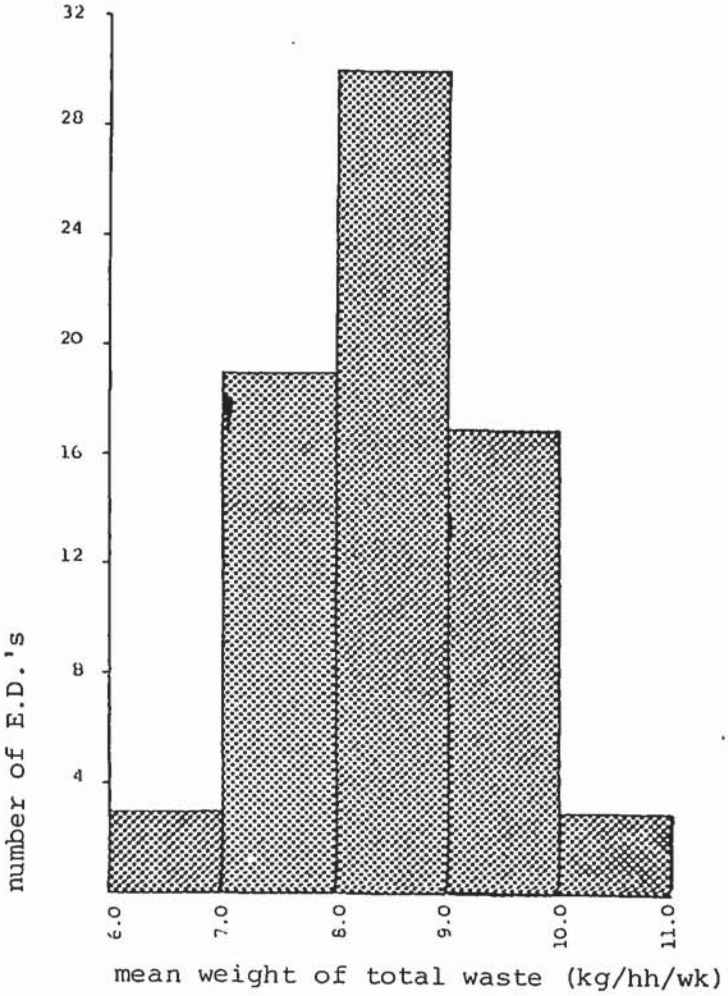

Fig. 7.7 Distribution of mean weight of total waste arisings per household for all Enumeration Districts in Erdington

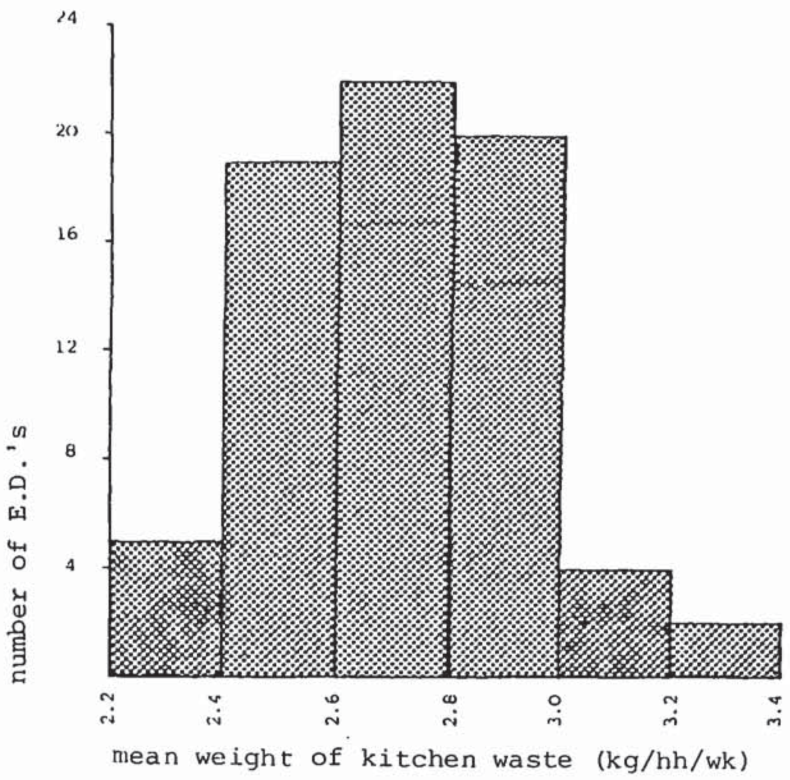

Fig. 7.8 Distribution of mean weight of kitchen waste per household for all Enumeration Districts in Erdington

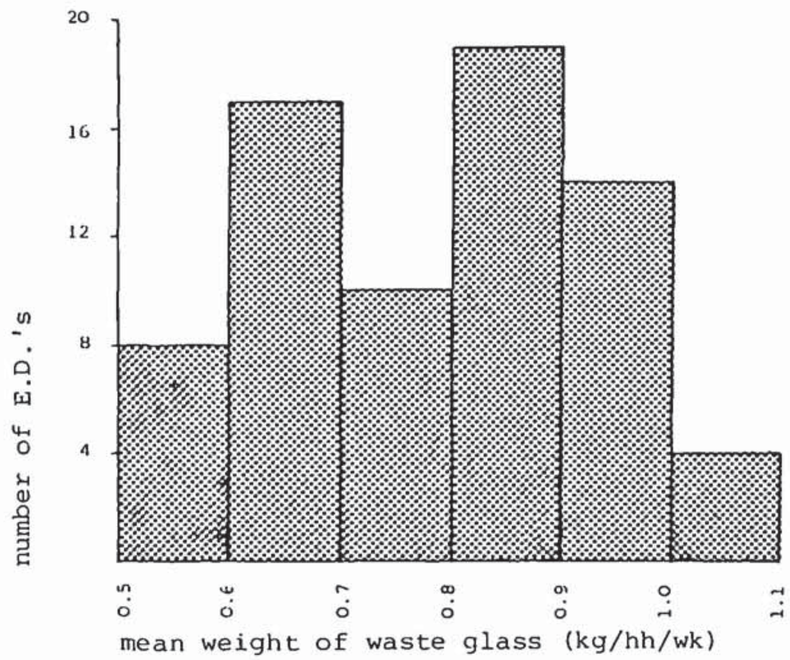

Fig. 7.9 Distribution of mean weight of waste glass per household for all Enumeration Districts in Erdington

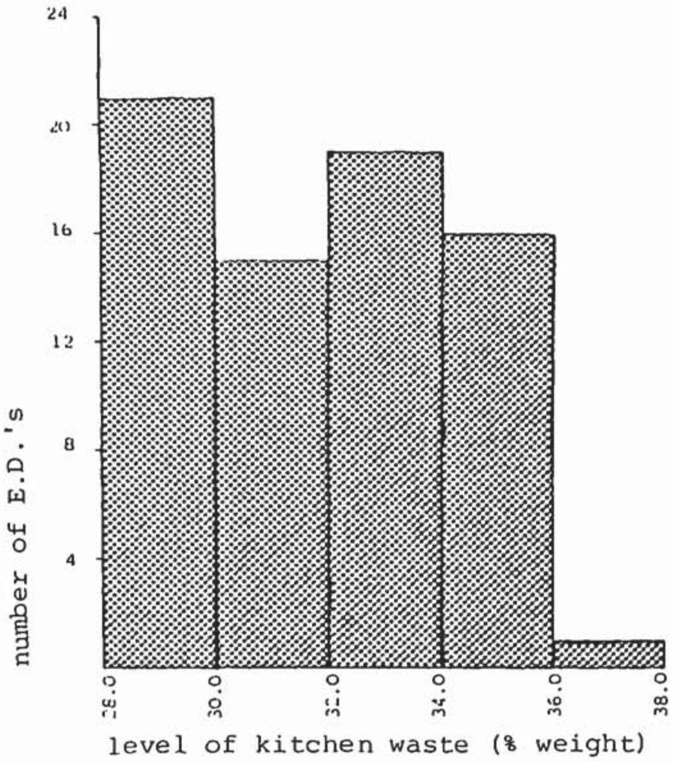

Fig. 7.10 Distribution of percentage levels of kitchen waste for all Enumeration Districts in Erdington

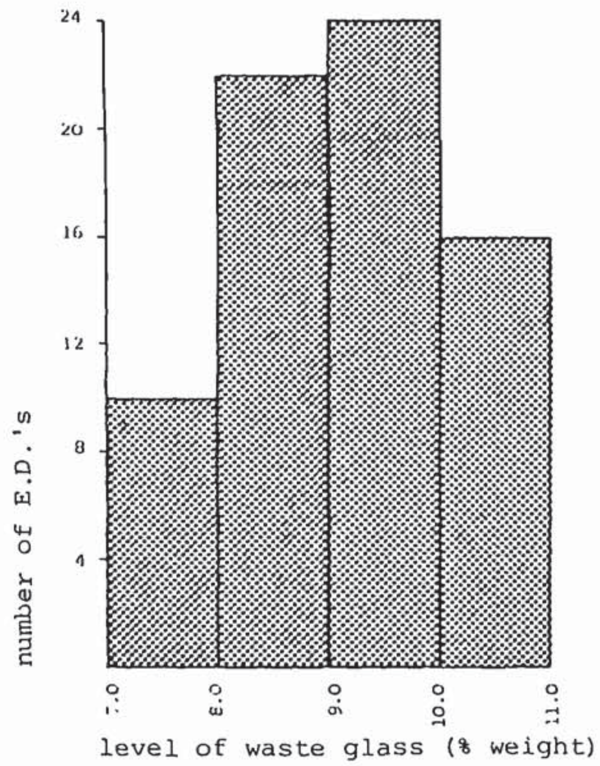

Fig. 7.11 Distribution of percentage levels of waste glass for all Enumeration Districts in Erdington

absolute weight and secondly in terms of percentages. The distributions are shown in Figures 7.7 to 7.11.

7.4.3 The frequency distributions highlight the substantial differences which exist in waste arisings between areas. The mean area level of total waste arisings for example varied from 6.69 kg/hh/wk to 10.44 kg/hh/wk. Mean area levels of one component kitchen waste, varied by as much as 1 kg/hh/wk from 2.24 kg/hh/wk to 3.34 kg/hh/wk. The highest mean area level of glass waste (1.06 kg/hh/wk) was more than twice the lowest mean area level of 0.50 kg/hh/wk. The distributions also highlight marked differences in the proportions of different waste components between areas. For example kitchen waste varied from 28.7% to 36.4% and glass waste from 7.0% to 10.4%. All these differences are particularly striking because they occur across a relatively small area.

7.4.4 The results suggest that conventional methods of area classification, which regard the enumeration district as the basic area unit and aggregate upwards, would risk submerging a substantial amount of important detail in waste arisings. The importance of regarding each ED as a separate entity as opposed to a basis for grouping is further illustrated by reference to the spatial configuration of area waste arisings. Figure 7.12 shows the spatial distributions of mean levels of total waste arisings in the Erdington ward. Although enumeration districts with similar mean total waste levels sometimes fall into areal clusters, frequently they do not. One of the objectives of conventional area analysis (e.g. Robson 1969, Herbert and Evans 1974, Walker 1975) is to build up spatially homogenous areas, and therefore contiguity is taken into account in the grouping procedure. It is evident from Figure 7.12 that the ED's could only be grouped on the basis of their locational characteristics at the expense of loss of detail in information about waste arisings.

7.4.5 The importance of maintaining the individual household as the fundamental unit of area analysis can be emphasised by focussing on an area which is ostensibly 'homogenous'. The Castle Vale estate in the south east corner of Erdington ward was planned and built as a single, municipal housing development. As such it would be grouped into a single category by conventional systems of area classification. However both waste quantity and composition vary between different parts of the estate and the pattern of variation exhibits discernable similarities with the spatial distributions of housing types. This can be seen by comparing Figure 7.15 showing the layout of the estate with Figure 7.12 (already referenced) and Figures 7.13 and 7.14 which show respectively the mean levels of total waste and the average percentage composition of kitchen waste and glass generated by different parts of the estate.

7.4.6 The lowest levels of mean total waste originate from the areas of multi-storey residential blocks in ED's 56 to 59 and 66 and 67. The highest total waste levels are associated with the separate family dwelling units in ED's 53 to 55. The percentage levels of kitchen waste vary almost inversely with the levels of mean total waste. The highest percentages

Fig. 7.12 Spatial distribution of mean levels of total waste arisings per household in Erdington

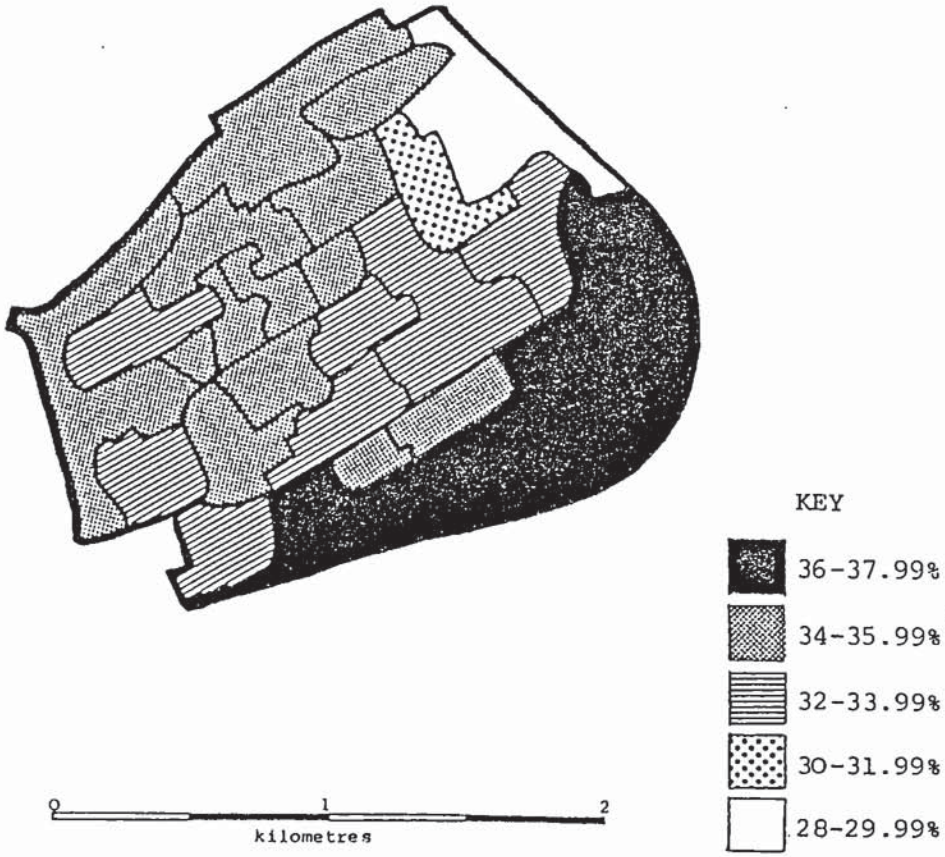

Fig. 7.13 Spatial distribution of percentage levels of kitchen waste on Castle Vale estate, Erdington

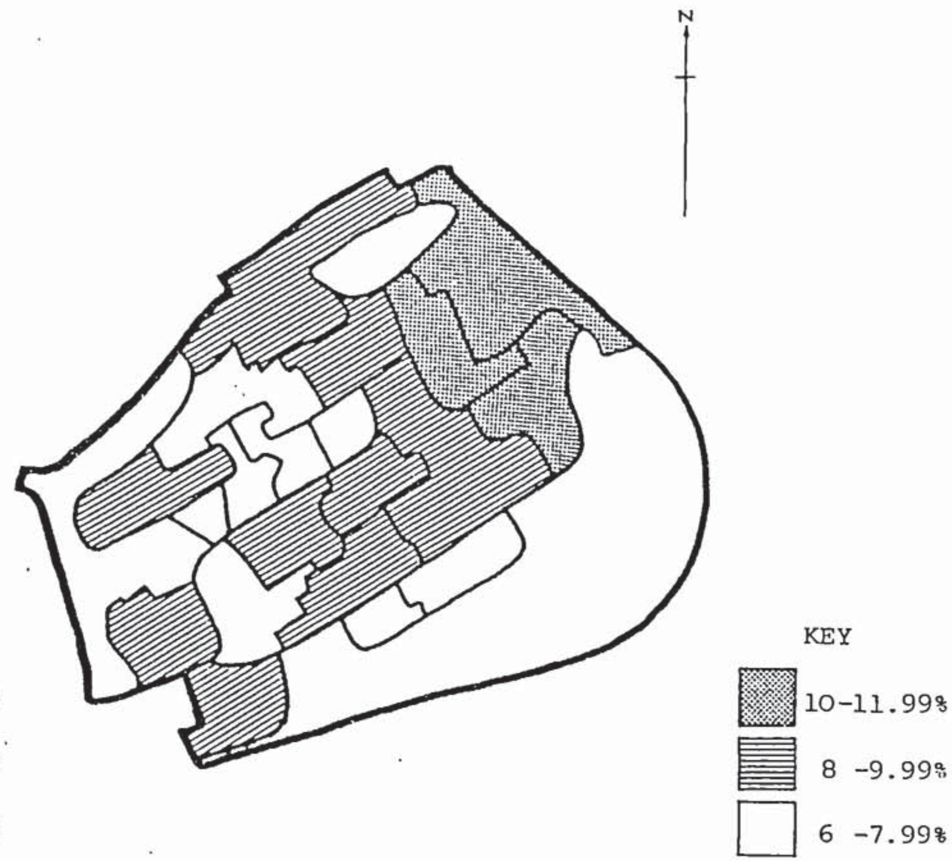

Fig. 7.14 Spatial distribution of percentage levels of waste glass on Castle Vale estate, Erdington

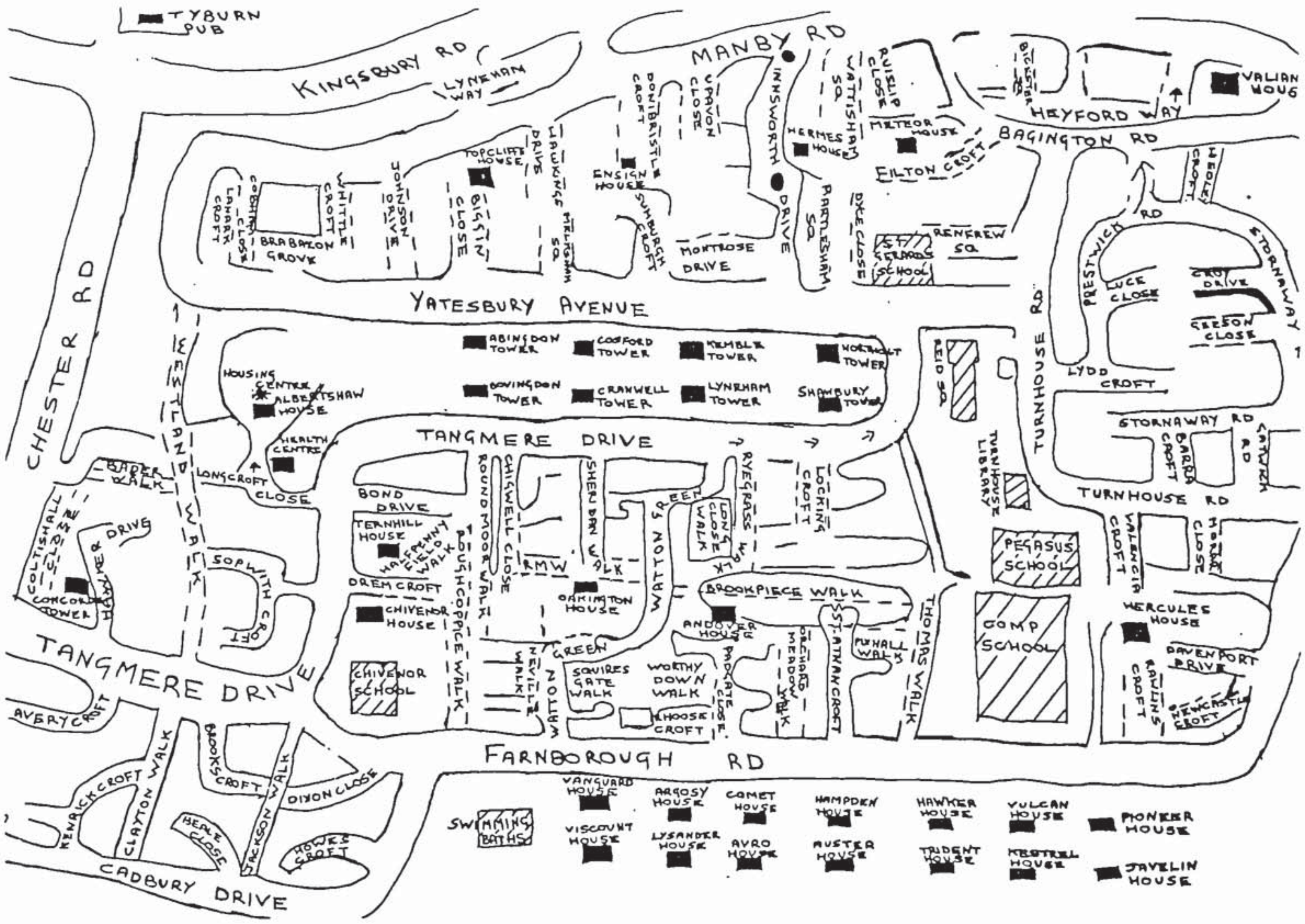

Fig. 7.15 Map showing the layout of housing on the Castle Vale estate

of kitchen waste are associated with the multistorey blocks and the lowest percentages with the family dwelling units. By contrast the pattern of distribution of percentage levels of glass mirrors the pattern of mean total waste. These differences illustrate the substantial variability in waste arisings within a relatively small area. Hence the need for an area prediction model based on the individual household is established empirically as well as theoretically.

7.4.7 The preceding discussion has demonstrated for the purposes of scientific interest the spatial variability in waste arisings and has shown the merit of using the approach to area modelling based on the individual household. The case studies carried out also represent a test of the performance of the area model, and the extent to which it satisfies the criteria derived from practical waste management needs. These points are taken up in the following discussion.

7.4.8 Paragraph 7.2.2 in this chapter established that the use of census data to obtain area estimates of waste arisings satisfies three of the five criteria set up on the basis of practical needs: it is simple and cheap and uses readily available data, it provides a basis for forecasting as well as for estimating waste arisings, and it is applicable at a range of spatial scales which correspond to the needs of waste management. What remains to be tested is the extent to which the method is 'accurate to the desired level' and is 'valid and reliable.'

7.4.9 In Chapter 3 it was established that too little was known about waste management decision-making to be precise about the appropriate level of accuracy of waste information, and also that the sensitivity of waste management decisions to variations in the quantity and composition of waste was likely to be different for each specific waste management context. However, it was also argued that existing methods of waste estimation are insufficiently accurate for waste management purposes, as evidenced by poor decision-making in the planning of waste facilities and in particular a tendancy to overestimate the quantity of waste arisings. In order to test the area prediction model developed in this research against existing methods of waste estimation, two sets of estimates of the waste levels within Birmingham Metropolitan Borough were obtained, one set using the area prediction model developed in this research and the other based on the standard technique currently used by local authorities, namely the 'Higginson method'.

7.4.10 A version of the Higginson method was devised which could be grossed up across the Birmingham area using data obtained from the West Midlands County Planning Department. The version was based on a 2-way cross-classification of households according to tenure and socio-economic group. This interpretation was a 'generous' one; 16 categories of household were specified in contrast to the 3 categories of household recommended by the DoE in order to ensure that the Higginson method was adequately represented. Table 7.6 gives the estimated waste arisings for Birmingham obtained by the area prediction model. For comparison, Table 7.7 gives the mean waste arisings per household obtained by the Higginson method. The 'errors' associated with the estimates of waste arisings in Table 7.6 were calculated from field survey data on the basis of sampling error (i.e. the variation in waste arisings between households sampled in each of the 24 categories was measured and weighted according to the number of households in each category in Birmingham, then pooled across all categories of household). They are of less interest in this context than the differences in the estimates of waste arisings obtained by the two different methods. For example the mean level of total waste per household estimated by the area prediction model was 8.56 kg/hh/wk whereas the corresponding figure estimated by the Higginson method was 9.98 kg/hh/wk.

7.4.11 The question arising from this comparison is why such a discrepancy should occur. Both approaches to area modelling grouped households according to 'occupation of household head' and tenure. However the Higginson approach did not discriminate between households according to their size. This research has established that there is a direct and powerful relationship between household size and waste arisings, and also a relationship between household size and occupation of household head (see Chapter 6). The exclusion of household size is therefore almost certain to result in bias in the waste generation coefficients associated with households grouped only according to tenure and occupation of the household head. This point casts doubt on the reliability of the results obtained by the Higginson method. By contrast, though it was not feasible to test exhaustively the area prediction model developed in this research, it was possible to compare the levels of waste arisings estimated by the model with the levels 'observed' during the field survey of households. Only a small number of households were sampled at densities of more than 5% during the field survey. The 'observed' mean levels of total waste for three of these ED's are given in Table 7.8 together with the corresponding expected levels as predicted by the area model. In each case the observed levels lie within 5 percentage points of the expected levels. (It was not possible to use the observed data on the three ED's to empirically test the Higginson method since information on the distribution of households according to the Higginson categorisation was not available at the ED level).

7.4.12 The points discussed in the paragraph above provide both theoretical evidence to challenge the estimates of waste arisings obtained by the Higginson method, and empirical evidence to validate the predictions of the area model developed in this research. This being the case, the area prediction model represents a substantial improvement in terms of both accuracy and reliability over the standard method of waste estimation in current use. The findings described in this chapter also have implications for the widely accepted 'average weight of waste per household' of

Table 7.6 Estimates of Household Waste Arisings in Birmingham MB Obtained by the Area Prediction Model

WASTE CATEGORY	MEAN WEIGHT OF WASTE '$\bar{x}$' kg/hh/wk	PERCENTAGE OF TOTAL WASTE	ERROR OF ESTIMATE 'σ' kg/hh/wk	ESTIMATED WASTE ARSISINGS FOR BIRMINGHAM MB ($\bar{x}$.356830) tonnes/wk	CONFIDENCE INTERVAL FOR $\bar{x}$ ($p < 0.05$) tonnes/wk
Total Waste	8.56	100.0	5.98	3054.69	± 7.00
Kitchen Waste	2.69	30.4	2.22	958.79	± 2.60
Garden Waste	0.62	7.0	1.68	219.68	± 1.97
Scrap Paper etc	0.58	6.5	0.56	205.85	± 0.66
Newsprint	1.09	12.3	1.24	389.61	± 1.45
Cardboard	0.45	5.1	0.46	160.17	± 0.54
Ferrous Metals	0.51	6.0	0.52	181.87	± 0.61
Non-Ferrous Metals	0.07	0.7	0.21	23.32	± 0.25
Textiles	0.25	2.7	0.82	87.52	± 0.96
Glass	0.80	9.0	1.05	287.12	± 1.23
Plastic Film	0.23	2.5	0.20	80.58	± 0.23
Dense Plastic	0.19	2.2	0.34	69.39	± 0.40
Misc. Combustible	0.47	5.5	1.08	171.01	± 1.26
Misc. Non-Combustible	0.20	2.2	0.73	70.54	± 0.55
Fines	0.42	4.7	1.13	149.22	± 1.32

Table 7.7 Estimates of Mean Levels of Household Waste Arisings in Birmingham MB Obtained by the Higginson Method

WASTE CATEGORY	MEAN WEIGHT OF WASTE (kg/hh/wk)	PERCENTAGE OF TOTAL WASTE
Total Waste	9.98	100.0
Kitchen Waste	3.18	31.9
Garden Waste	0.65	6.5
Scrap Paper etc	0.70	7.0
Newsprint	1.24	12.4
Cardboard	0.54	5.4
Ferrous	0.60	6.0
Non-Ferrous	0.08	0.8
Textiles	0.31	3.1
Glass	0.97	9.7
Plastic Film	0.27	2.7
Dense Plastic	0.23	2.3
Misc. Combustible	0.53	5.3
Misc. Non-Combustible	0.23	2.3
Fines	0.45	4.5

Table 7.8 Observed Versus Expected Levels of Mean Total Waste Arisings for Three Enumeration Districts

ENUMERATION DISTRICT CODE	NUMBER OF HOUSEHOLDS	PERCENTAGE OF HOUSEHOLDS SAMPLED	EXPECTED LEVEL OF MEAN TOTAL WASTE ARISINGS (kg/hh/wk)	OBSERVED LEVEL OF MEAN TOTAL WASTE ARISINGS (kg/hh/wk)
CNAJ19	196	11	10.28	10.25
CNBF37	191	16	9.61	9.13
CNBF39	180	.8	8.98	8.61

'in excess of 10 kg per week'. There have been previous warnings that the way in which waste generation figures are currently obtained may tend to overestimate the true level of waste arisings (e.g. DoE 1971, Even 1981), as well as empirical evidence from waste manangement practice which suggests that the estimates of waste arisings used in the design of plant and equipment are too high (e.g. Municipal Engineering 1979). This research reinforces those warnings. One possible explanation is that many 'interpretations' of the Higginson method tend to neglect multioccupancy dwellings (e.g. Ling 1976, Birch 1976), perhaps because of the difficulties of sampling households which use communal disposal facilities.

7.5 Conclusions

7.5.1 A number of important conclusions have emerged from this chapter:

(1) The potential strength and usefulness of an area prediction model based on individual households was demonstrated, and also its sensitivity in discriminating between the waste arisings of different areas.

(2) The results of the case study application of the area model showed that, in practice, households do tend to group into separate neighbourhoods each with a distinct waste 'profile'. The case study results also showed that there are substantial differences both between area levels of total waste, and between

area levels of individual waste components, even within a relatively small zone.

(3) The findings of the area prediction model in relation to Birmingham suggest that the mean level of total waste arisings for a large area may be lower than predicted by conventional methods of waste estimation.

7.5.2 The area prediction model described in this chapter was designed on the basis of a set of criteria derived from practical waste management needs. In general, the model developed was able to satisfy these criteria, although it was not possible to determine the precise extent to which the accuracy of the model matched the sensitivity of decisions in waste management. However, the area prediction model was shown to represent a substantial improvement in terms of accuracy and reliability over the widely used existing method of waste estimation. The case studies carried out in this chapter have also borne out the rationale for using the individual household as the basis for the area estimation of waste arisings, and have demonstrated the flexibility of the area modeling technique. A final comprehensive appraisal of the waste estimation method developed in this research against conventional methods for waste estimation is given in Chapter 9.

CHAPTER EIGHT

EXTENDING THE BOUNDARIES OF THE WASTE ARISINGS MODEL

8.1 Introduction and Aims

8.1.1 Up to this point the thesis has discussed the characteristics of household waste in one locality and in a single time period. This has been because of the 'case study' method used to generate data. The key objectives have been to test the hypothesis that households systematically produce different types and amounts of waste, and to construct a predictive model on that basis. Clearly however, the model resulting from this process is specific to the West Midlands County, and particular to the survey period (Autumn 1982). In order to be able to apply the existing model in wider contexts, this chapter discusses ways of extending the boundaries of the research to include regional, seasonal and trend factors.

8.1.2 The way in which regional, seasonal and trend factors combine with household characteristics to determine the nature of waste arisings can be expressed concisely in mathematical form:

$$W_{ijk} = \sum_{a} (W_a)_{ijk} \cdot n_a$$

Where W_{ijk} is the quantity of waste generated in a given area by all households of type a in region i, season j and point in trend k and $(W_a)_{ijk}$ is the waste generation coefficient associated with households of type a in region i, season j and point in trend k

and n_a is the number of households of type a within the area.

For reasons of practicality and research tractability the factors represented by 'i', 'j', and 'k' in the above expression have been held constant throughout the experimental part of this research, while examining the effects of 'a'. In each successive section of this chapter the assumptions of constancy are progressively relaxed in order to study the effects on waste arisings of first regional, then seasonal and then trend factors.

8.2 Regional Factors

8.2.1 This section discusses the nature of regional factors, together with the mechanisms by which they affect waste generation and the level of spatial resolution at which they operate. Following this review, possible alternative options are given for modifying the existing 'household model' in order to incorporate the effects of regional factors.

8.2.2 Regional factors lead to systematic variation in the waste arisings associated with households of similar type but located in different regions. A number of underlying influences account for these regional differences:

(1) Urban/rural distributions

Different patterns of food consumption and food wastage have been identified among regions which vary in terms of their relative degree of urbanisation (Adelson et al 1963, Wenlock 1979, MAFF 1982). These patterns reflect a varying dependence on the use of fresh foods and seasonal products and varying behaviour in the disposal of food leftovers. In addition, smoke control zones are a feature of urban areas which have a bearing on the type of domestic heating used and hence on the nature of waste arisings.

(2) Industrial, Agricultural and Employment Structure

Waste arisings are subject to variation according to the characteristics of the regional economy as a result of a number of factors:

(a) Employment structure: the level of unemployment and the level of female economic activity is likely to affect waste arisings through household income and the division of domestic tasks.

(b) Industrial characteristics: certain industries have a distinctive effect on waste generation. For example the free coal ration is a long-standing tradition of mining areas and is reflected in the ash content of household waste (Brown 1969).

(c) The price and availability of particular types of agricultural produce (and the waste arisings associated with such produce) will vary from region to region according to the predominant form of agriculture being practiced.

(3) Market Area

The location of a household with respect to the market area served by manufacturing and retail companies may affect the availability of specific types of commodity. For example the distribution of brand-name products is linked to the geographical network of retail chains in Britain (Davies 1976, Kivell 1980).

(4) Waste Collection/Disposal Policy

The variation in waste collection and disposal policy between administrative areas in the UK is likely to influence waste arisings in a number of respects:

(a) The method of household waste collection (e.g. sack, hod or kerbside collection) and the type and capacity of refuse container supplied will affect the disposal capacity available to the household and the interpretation by refuse collectors of what constitutes 'legitimate household waste' (e.g. where sacks are distributed only bagged items are accepted for disposal).

(b) The provision and charging rate for special bulk waste collection services together with the provision of civic amenity sites are likely to affect the pressure put on the regular collection service.

(c) The policy of the collection authority towards the removal of garden waste is likely to affect the quantity of this type of waste deposited in the dustbin. In some areas the collection of garden waste is explicitly disallowed while in other areas special sacks or tickets can be bought to pay for its collection.

(5) <u>Pre-Collection Recycling</u>

The amount of household waste recycled through bottle banks and through paper and can recycling schemes is likely to vary on a regional basis according to the availability of and ease of access to these facilities.

(6) Socio-cultural Factors

Regional variations in waste arisings have been attributed to spatial variations in socio-cultural factors, particularly those affecting dietry behaviour (Harrison et al 1975).

(7) Climatic Factors

Climatic factors may affect waste arisings through intervening mechanisms such as the extent of use of domestic heating and types of food consumed (see section 8.3.2).

8.2.3 The spatial pattern of regional factors will be different for different factors. In certain cases the influence of factors is delineated by identifiable boundaries. Waste collection and disposal policy for example and the placement of bottle banks are linked to local authority areas. The degree of urbanisation and the type of industrial structure are also reasonably well reflected in the boundaries of administrative areas. Certain other groups of factors such as socio-cultural characteristics and climate are spatially amorphous at the regional scale and the demarcation of homogeneous zones is possible only at much lower levels of resolution.

8.2.4 Table 8.1 gives the composition by percentage weight of household waste sampled within a selection of waste disposal authority areas within the UK. No statistical analysis has been carried out on the data bacause the means of collection, methods of sorting and classification and the timing of the various surveys from which the data is assembled were *not* consistent with one another. However there are broad differences in the data among the WDA's which imply that household waste displays regional distinctions. The differences can be seen more clearly by grouping WDA's for which the waste information is available into metropolitan and non-metropolitan counties. Waste from the two metropolitan counties is similar in terms of mean percentages (although there are notable intra-regional differences in waste composition between the six collection areas in Merseyside). Distinct regional variations are evident among the non-metropolitan counties. For example, levels of paper vary from 15.8% in Oxfordshire (where separate paper collections were organised at the time of the survey) to 50.9% on the Isle of Wight. The level of screenings ranges from 8% in Dorset to 49.2% in Durham (B) - a traditional coal mining area.

8.2.5 The above discussion has focussed on regional factors operating within the UK. However each group of factors has an international dimension in addition to a national dimension. Differences in waste arisings across international boundaries tend to be more clearly defined than differences within national borders. Additional spatial factors which affect waste arisings at an international level include:

(1) Charges levied on the household for waste collection which are linked to the quantity of waste removed as in Sweden (Lidgren 1981). These will tend to modify the propensity of households to generate waste (Wertz 1976).

(2) International differences in packaging legislation and duty on alcoholic drink which influence the type and quantity of beverage containers in the waste stream.

(3) International industrial, agricultural and socio-cultural differences.

Tables 8.2 to 8.5 compare waste arisings from four European countries. Although there are certain disparties between the tables in the way in which of waste categories are defined, marked contrasts are nevertheless evident in the levels of various types of waste. The level of paper varies between 27% in Denmark and 48% in Sweden for example, and the level of kitchen waste varies between 18% in Sweden and 38.5% in Norway.

Table 8.1 Composition of Household Waste by Selected Regions (% weight)

Non-metropolitan Counties	Vegetable & Putrescibles	Paper	Metals	Textiles	Glass	Plastics	Unclassified	Screenings 2cm	Population
Berkshire	22.13	25.99	8.01	4.80	11.91	6.89	8.18	12.09	694,200
Cheshire	35	21	7	4	10	6	5	12	930,800
Dorset	30	35	7	3	9	5	3	8	591,990
	31.3	15.31	6.66	4.28	6.58	5.88	1.82	28.17	
Durham (a) A	40.42	23.36	7.49	4.56	8.59	7.28	1.18	7.12	603,200
B	22.17	7.25	5.84	4.00	4.57	4.48	2.47	49.22	
Isle of Wight (b)	19.8	50.9	7.2	2.7	6.4	2.6	1.3	9.1	116,000
Kent (c)	15.5	28.3	9.7	3.3	13.2	6.5	6.8	16.7	1,456,800
Leicestershire	27.63	28.24	7.64	7.14	14.32	4.46	1.89	8.68	845,500
N Yorkshire	14.84	34.02	8.81	5.40	9.73	4.64	5.42	17.1	667,400
Oxfordshire (d)	33.9	15.8	9.0	2.5	9.4	2.9	1.0	25.5	550,100
Suffolk (e)	28	21	7	3	11	4	2	24	602,900
Population Weighted mean	25.3	25.9	8.0	4.2	10.9	5.3	4.3	16.1	7,058,890
Metropolitan Counties	**Vegetable & Putrescibles**	**Paper**	**Metals**	**Textiles**	**Glass**	**Plastics**	**Unclassified**	**Screenings 2cm**	**Population**
Mean	36.13	28.2	6.6	3.02	8.63	3.87	3.08	9.87	
	37.0	31.8	6.8	1.5	7.5	3.6	2.8	9.0	
	33.50	29.3	6.5	2.2	8.8	4.0	3.3	12.4	
Merseyside (f)	39.5	24.0	8.2	4.3	9.0	3.4	4.1	7.5	1,521,000
	36.4	28.6	5.6	3.9	7.1	4.0	2.3	12.1	
	34.8	30.0	6.0	3.4	10.5	4.3	2.9	8.1	
	35.6	29.2	6.5	2.8	8.9	3.9	3.1	10.1	
S Yorkshire (g)	35.46	31.12	5.34	1.7	9.31	2.97	1.79	12.31	1,295,600
Population weighted mean	35.8	29.5	6.0	2.4	8.9	3.5	2.5	11.0	2,816,600
Non-metropolitan Counties	25.3	25.9	8.0	4.2	10.9	5.3	4.3	16.1	28,299,700
Metropolitan Counties	35.8	29.5	6.0	2.4	8.9	3.5	2.5	11.0	20,243,475
Population weighted mean	29.7	27.4	7.2	3.4	10.1	4.5	3.5	14.0	48,543,175

(a) Two samples; (b) 1975; (c) Mean 1976/80; (d) 1974 Separate paper collection; (e) 1978; (f) Six samples; (g) 1975

Source: Moore 1982

Tables 8.2 - 8.5 Contrasting Composition of Household Waste in Four European Countries (% weight)

WASTE CATEGORIES	% WEIGHT
Paper	27.3
Cardboard	7.4
Animal Products	1.8
Vegetable Products	33.2
Textiles	1.9
Rubber, Leather	0.4
Plastics	5.9
Other combustibles	5.6
Clear glass	4.0
Coloured glass	3.8
Scrap Iron	2.4
Other Metals	2.0
Other non-combustibles	4.3
	100.0

Table 8.2 Denmark

WASTE CATEGORIES	% WEIGHT
Glass	10.5
Wood	2.1
Plastics	5.9
Metals	8.4
Mineral Components	13.9
Paper	29.8
Textiles	8.0
Vegetable Waste	21.4
	100.0

Table 8.3 Austria

WASTE CATEGORIES	% WEIGHT
Paper	33.5
Food waste	38.5
Textiles	3.1
Rubber, Leather	1.1
Plastics	5.1
Other combustibles	5.3
Metals	4.0
Glass	5.1
Other non-comubustibles	1.4
Fines 10 mm	2.9
	100.0

Table 8.4 Norway

WASTE CATEGORIES	% WEIGHT
Paper	48
Plastics	5
Textiles	2
Rubber, Leather	1
Glass	9
Iron, other metals	5
Kitchen waste	18
Miscellaneous	12
	100

Table 8.5 Sweden

Source: Bridgewater and Lidgren 1982

Incorporation of Regional Factors into the Household Waste Model

8.2.6 Regional variations in the waste generating characteristics of households can potentially be incorporated into the existing household prediction model through a number of different means. The first approach is to recalibrate the model empirically in each area where there is evidence of a shift in underlying spatial factors. Having previously specified the form of the model and with prior knowledge of the extent of waste variation within categories of household, the task of recalibration would be considerably less arduous than the sampling exercise carried out to calibrate the model originally. With the aid of the research findings outlined in Chapter 5, sampling could be carried out on a centrally planned and statistically well determined basis.

8.2.7 The second possible approach to the incorporation of regional factors into the household model is to develop a taxonomy of regions as a basis for predicting the waste arisings from a specified type of household within a specified type of region. Similar households within similar regions would be expected to be homogenous in respect of their waste arisings while similar households in different regions would be expected to generate different types and amounts of waste. In terms of the general model outlined in section 8.1.2, the regional factor ('i') would have a finite number of scale positions, each corresponding to a distinct type of region. Although the data does not exist to classify regions in the UK on the basis of the waste generating characteristics of the households within each region, it may be possible to base a regional taxonomy on an existing system of area classification. A number of alternative existing systems of area classification are available (Davies 1983). Their relevance to the problem of estimating waste arisings depends ultimately on the extent to which they are able to group together areas in which similar household types possess similar waste generating characteristics. Alternatively, it may be desirable to carry out a purposive classification of areas using variables which are hypothesised to account for variations in waste arisings between regions.

8.2.8 In summary, subjects for further research in the context of developing a full-scale regional waste arisings model include:

(1) The measurement of the extent of inter-regional variation in waste arisings through the controlled sampling of households in different regions, and the testing of hypotheses relating to 'regional factors'.

(2) The investigation of the potential benefits of using an existing system of area classification to group together regions within which similar households have similar waste generating characteristics.

(3) The investigation of the possibility of developing a purposive classification to meet the specific needs of waste estimation.

8.3 Seasonal Factors

8.3.1 This section identifies the factors accounting for seasonal variations in waste arisings and suggests how the effects of seasonality might be incorporated into the household prediction model.

8.3.2 Systematic variations in household waste arisings occur throughout the year as a result of a cyclical movements in a number of aspects of household behaviour. These may be summarised under the general headings of:

(1) Food Consumption

The quantity and type of food consumed by a household will change in response to a variety of factors including:

(a) Growing season. This affects particularly the price and availability of certain types of fruit and the consumption of home-grown produce.

(b) Calorific intake. The average calorific intake of a household is higher in the winter than in the summer (MAFF 1982).

(c) Consumption of (non-fresh) seasonally related foods e.g. soft drinks and ice-cream.

(2) Food Wastage

The amount of waste food fed to wild birds increases during the winter period (Wenlock 1979).

(3) The Effect of Temperature on Solid Fuel Consumption

A well established formula exists which links changes in ambient temperature to air pollution from domestic coal fires. The formula is based on the 'degree-day concept' in which the degree-day is a joint index of the number of days on which the temperature falls below a specified threshold (60°F, 15°C) and the size of the shortfall. It is probable that a similar relationship could be shown to exist between temperature and the generation of residual ash from solid fuel.

(4) The Generation of Garden Waste

Most garden waste is produced either during the high growth period in the spring or during leaf fall in the Autumn.

(5) National and School Holidays

The size of the household effectively increases during holidays as a result of the extra number of meals taken at home. In addition, consumer spending tends to increase during holidays which coincide with events in the religious and commercial trade calendar. The level of waste input to GLC waste disposal facilities reaches an annual peak during the Christmas period in the last week of December and the first two weeks in January (Townend 1979).

8.3.3 Each group of seasonal factors varies over different time periods. In general, climatic factors take effect over longer periods than events in the religious and commercial calendar. There is empirical evidence of systematical cyclical variation between quarters of the year and also between successive four week periods in the year. Table 8.6 shows the most recent national quarterly analysis of waste carried out in 1977. The seasonal variation is most marked in relation to:

(a) the 'screenings' category which ranges from 10% by weight of total waste in July to 21% of waste in January.

(b) the 'vegetable and putrescible category' which varies inversely with the level of screenings, from 28% of waste in July to 21% in January.

Table 8.6 1977 National Quarterly Analysis of Household Waste (weight per household)

WASTE CATEGORIES		1977 Jan	April	July	Oct	Mean
Total Waste	%					
	kg	10.3	10.4	9.6	10.2	10.1
Vegetable and Putrescible	%	21	22	28	27	25
	kg	2.1	2.3	2.7	2.8	2.5
Paper and Board	%	26	26	26	26	26
	kg	2.7	2.7	2.6	2.6	2.7
Metals	%	8	9	9	8	9
	kg	0.9	0.9	0.9	0.9	0.9
Textiles	%	3	3	3	3	3
	kg	0.3	0.4	0.3	0.4	0.3
Glass	%	10	11	12	10	11
	kg	1.1	1.2	1.2	1.0	1.1
Plastics	%	4	5	6	6	5
	kg	0.4	0.5	0.6	0.6	0.5
Unclassified	%	7	9	5	8	7
	kg	0.7	0.9	0.5	0.8	0.7
Screenings 2cm	%	21	15	10	11	14
	kg	2.1	1.6	0.9	1.2	1.4

Source: Higginson 1981

8.3.4 A US study of household waste (Richardson 1974) found statistically significant differences in levels of waste arisings between 13 four week periods (total = 1 year). The American study was confined to 'well-established neighbourhoods in which seasonal variation in waste arisings was closely associated with variations in quantities of garden waste and in particular with grass cuttings and tree prunings in the Spring and with collected leaves in the Autumn.' As a result, the highest measured quantities of total waste coincided with the four week periods in the Spring and Autumn, while lowest levels of total waste were found in January and February. These results are unlikely to be broadly representative of the UK. At a more general level, however, they are interesting because they demonstrate a clear interaction between seasonal factors ('growing season') and socio-economic factors ('access to/size of garden').

Incorporation of Seasonality into the Waste Arisings Model

8.3.5 There is evidence of substantial seasonal differences in waste arisings and evidence of interaction between seasonal and socio-economic factors, particularly in relation to specific categories of waste such as garden waste. In order to develop a thorough understanding of the factors underlying seasonal changes in household waste as a basis for predictive modelling, it would be necessary to study the seasonal variation in individual component categories of waste among different types of household. Areas for further research therefore include:

(1) The measurement of the extent of seasonal variation by controlled sampling of a subset of the households originally surveyed, and the testing of hypotheses relating to 'seasonal factors'.

(2) The investigation of the possibility of interaction between seasonal and regional factors, through the seasonal analysis of waste arisings on a regional basis.

8.4 Trend Factors

8.4.1 In addition to the cyclical changes in waste arisings which occur over a single year there are longer term trends over periods of years due to fundamental, structural changes in the mechanisms of waste generation. This section discusses the factors which underlie the trends in waste arisings and considers ways of incorporating a 'forecasting dimension' into the household prediction model.

8.4.2 Long term changes in the quantity and composition of waste arisings can be attributed to a variety of factors:

(1) Changes in the size and nature of the waste elements associated with consumer goods (see Chapter 2). The principal underlying reasons are changes in packaging and processing methods subject to the constraints of legislation particularly those relating to consumer protection and food hygiene.

(2) Changes in the quantity and type of consumer goods purchased. Shifts in commodity prices and in the prices of substitute or complementary goods, together with changes in consumer tastes and preferences, will affect the level of consumption of different types of consumer items.

(3) Changes in legislation, tariffs and fiscal penalties and incentives. Waste arisings are affected both directly and indirectly by a variety of types of statutory and non-statutory controls. One example is legislation relating to domestic coal burning in cities.

(4) Shifts in the probalistic relationships between the 'indicators' used in the household model and the underlying constructs which they represent. For example 'tenure' serves partly as a surrogate for income in the household model. Although the model is able to take account of changes in income which result in a redistribution of households among categories of tenure, it will not respond to changes in income which have no effect on tenure.

8.4.3 Table 8.7 shows the general trend in the quantity and composition of household waste from 1963 (when regular national surveillance of household waste arisings first began) until 1979. The data indicates that during this period the proportion of 'screenings' declined from 38.8% to 14.9% and 'vegetable

Table 8.7 National Analyses of Household Waste from 1963 to 1980* (Weight per Household per Week)

WASTE CATEGORIES		1963	1967	1968	1969	1970	1972	1973	1974	1975	1976	1977	1978	1979	1980
Total Waste	kg	14.1	13.0	13.3	12.8	13.5	11.7	11.6	10.7	11.6	10.2	10.1	10.9		
Vegetable & Putrescible	%	14.1	15.5	17.6	19.5	24.5	19.5	18.1	21.3	20	19	25	29	24	26
	kg	2.0	2.0	2.3	2.5	3.3	2.3	2.1	2.3	2.4	2.0	2.5	3.2	2.59	
Paper & Board	%	23.0	29.4	36.9	37.9	36.8	30.5	32.7	26.8	30	24	26	27	29	29
	kg	3.2	3.8	4.9	4.9	5.0	3.6	3.8	2.8	3.4	2.4	2.7	3.0	3.21	
Metals	%	8.0	8.0	8.9	9.7	9.2	8.7	8.8	8.5	8	8	9	7	8	8
	kg	1.1	1.0	1.2	1.2	1.3	1.0	1.0	0.9	0.9	0.8	0.9	0.8	0.88	
Textiles	%	2.6	2.1	2.4	2.3	2.6	3.0	3.1	3.5	3	4	3	4	4	3
	kg	0.4	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.3	0.4	0.3	0.4	0.47	
Glass	%	8.6	8.1	9.1	10.5	9.0	10.4	10.5	9.5	9	9	11	9	10	10
	kg	1.2	1.1	1.2	1.3	1.2	1.2	1.2	1.0	1.1	0.9	1.1	1.0	1.13	
Plastics	%		1.2	1.1	1.4	1.4	1.9	2.0	2.9	4	5	5	5	7	7
	kg		0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.5	0.5	0.6	0.76	
Unclassified	%	4.9	4.7	2.1	1.5	1.6	6.1	6.1	6.9	8	14	7	6	6	14
	kg	0.7	0.6	0.3	0.2	0.2	0.7	0.7	0.7	0.9	1.4	0.7	0.6	0.62	
Screenings 2cm	%	38.5	31.0	21.9	17.2	14.9	19.9	18.7	19.8	18	18	14	11	12	4
	kg	5.5	4.0	2.9	2.2	2.0	2.3	2.2	2.1	2.1	1.0	1.4	1.2	1.37	

* All analyses carried out in October

Source: Higginson 1981

and putrescible' waste and 'paper and board' waste increased from 14.1% to 24.5% and from 23.0% to 36.8% respectively. The weight of plastics increased by nearly four times in the ten years between 1969 and 1979, from 0.2 kg/hh/wk to 0.76 kg/hh/wk. The period 1963 to 1979 spans a time of expanding use of both convenience foods and convenience fuels, with an associated increase in the quantities of packaging waste and a reduction in the amounts of solid fuel residuals. These kinds of changes have had important consequences for waste management. The reduction in the ash content of waste for example has increased the suitability of household waste for the manufacture of waste derived fuel, while the occurence of unforseen quantities of plastics in waste has created problems for the incineration of household waste (see Chapter 3).

Incorporation of Trend Factors into the Waste Arisings Model

8.4.4 The following paragraphs review existing methods of waste forecasting and then consider ways in which a 'forecasting dimension' might be incorporated into the household prediction model in order to improve on 'current best practice'. There are a number of different generic approaches to the problem of waste forecasting. These represent a scale of sophistication from simple extrapolative methods to complex statistical modelling. Some of the approaches are in current use or have been applied in previous studies, others remain to be tested.

8.4.5 The most basic approach to waste forecasting is one of 'curve fitting' which involves the extrapolation of a time series of past chronological data on waste arisings. The method was applied by Thomson (1978) to Birmingham waste data. Thomson constructed separate regression equations for weight and volume of waste and five waste categories from four different types of property. The classification of property used was based on the traditional Higginson groupings. The limitation of this type of method is that it assumes fixed rates of change in waste arisings and does not take account of the factors which cause waste to be generated. The approach depends on the inertia of the waste generation system. Berry (1978) argues that the assumption of 'continuity' which is implicit in Thomsons's approach is valid for a short range forecasting exercise, but not for a long range exercise. A second operational disadvantage of the method also pointed out by Berry is that detailed chronological records of waste arisings are not available to many of the Waste Disposal Authorities in the UK.

8.4.6 A second approach to the forecasting of waste arisings is based on the 'input/output' concept. This approach has been discussed in detail in Chapter 1. A simple version of an input/output model has been developed in the UK by LGORU (1969) who obtained projections for the rate of change in the level of domestic consumption of the main classes of materials which contribute to the household waste stream (e.g. paper, glass etc). Fundamental to the LGORU method is the assumption that the component categories of waste will change by the same scale factor as the corresponding types of material in consumer goods. No allowance is made for leaks in materials via other disposal channels or for the time lag between consumption of the goods by the household and their ultimate disposal. LGORU give no estimates of error for the forecasts of the changes in the domestic consumption of materials which they obtain, and this tends to lend spurious certainty to the results. The method was tested for Birmingham by Thomson using a process of postdiction. Thomson reports that the results did 'not agree with subsequent observations'.

8.4.7 The third alternative approach to waste forecasting involves deriving 'waste generation coefficients' either for explanatory variables or for waste production units, and combining the coefficients with future projections of the variables or waste production units. At the simplest level this type of 'behavioural' approach may involve combining estimates of waste generated per capita (or per employee) with estimates of the growth rates in the size of population (or in the number of employees). This technique has been adopted by a number of previous studies (reported in Berry 1978). It is also commonly used by local authorities as a technique for preparing waste forecasts for waste disposal plans (LGORU 1975). A slightly modified form of the approach was used by the Technical Institute of the University of Berlin (Goosmann 1980) who allocated one of 3 different per capita estimates of waste arisings to each area of Berlin depending on the taxonomic group or 'cluster' in which the area was grouped. The limitation of this technique lies in the fact that it is not based on the fundamental unit of waste generation and does not take account of the social, economic and technical factors which cause waste to be produced.

8.4.8 In the context of waste forecasting, a more technically valid behavioural unit is the individual household, which forms the basis of the model developed in this research. There are a number of levels of sophistication at which a forecasting dimension could be incorporated into the existing household prediction model:

(1) Waste generation coefficients from the household model could be combined with future projections of the numbers of households of different types within a given area. Future projections of households could potentially be obtained by applying the technique of 'category analysis' (see Wootton and Pick 1967, or Chatterjee and Khasnabis 1973) to available forecasts of the appropriate socio-economic variables.

(2) In order to take account of such factors as changes in consumer tastes and preferences and changes in the size and nature of the waste elements associated with consumer goods a more sophisticated procedure could be developed. This would involve interfacing a number of different types of projections:

(a) projections of future numbers of households of different types.

(b) projections of the future demand for different classes of consumer goods by each type of household.

(c) projections of the future types of materials used in the packaging and manufacture of different classes of consumer goods.

The forecasting of the future demand for consumer goods is the subject of intensive market research. Forecasts of the future uses of packaging materials in consumer goods can be obtained from appropriate statistical reviews (e.g. Mills 1980, Phillips and Drew 1981).

8.4.9 Areas for further research in the development of a waste forecasting arm to the household model therefore include:

(1) Obtaining projections of the household types defined by the model.

(2) Establishing an interface matrix between the variables in the household model and those used in market forecasting, coupled with data on future developments within the packaging industry.

8.5 Conclusions

8.5.1 This chapter has established a number of important points which are summarised below:

(1) The research has examined only one dimension of a multi-dimensional problem. The existing form of the waste arisings model is confined in scope to the prediction of the variation in waste arisings between households.

(2) Available sources of information indicate that there is systematic variation in the quantity and composition of waste arisings generated by similar types of household located in different regions and also systematic seasonal and long term variation in waste arisings.

(3) There are a variety of ways in which the existing household prediction model can be extended to take account of regional, seasonal and long-term changes in waste arisings. The development of these additional dimensions to the household model represent areas for further research.

8.5.2 On the basis of a review of currently available methods for forecasting waste arisings the potential has been established for improving on 'current best practice'. A programme of follow-up work aimed at advancing this and other areas of the research is discussed in the final, concluding chapter of this thesis.

CHAPTER NINE

CONCLUDING APPRAISAL OF THE RESEARCH AND RECOMMENDATIONS FOR FURTHER WORK

9.1 Introduction and Aims

This chapter provides a final concluding appraisal of the research together with recommendations for follow-up work. The chapter is divided into three sections. The first section evaluates the findings of the research against the two key aims set out in the first chapter of this thesis. The second section makes an appraisal of the research work itself, in terms of the main strengths and weaknesses in the research method and in the various techniques adopted. The third section examines the broader persepectives and future directions of the work.

9.2 Evaluation of the Research Findings

9.2.1 The specific conclusions of the research in relation to each of the four research objectives have been set out at the ends of each of the relevant chapters. This appraisal discusses the research findings in terms of the two key research aims, namely:

(1) to contribute to the scientific understanding of the process of household waste generation.

(2) to develop a method of waste estimation to respond to the practical needs of the wastes industry.

Section 1.3 in Chapter 1 established that the process of waste generation at the household level was not well understood, largely as a result of the fact that existing studies have either tended to neglect the basic social, economic and technical factors underlying waste generation, or have tended to begin with the wrong fundamental unit of aggregation (e.g. the individual population member or the census area instead of the household).

9.2.2 This research has made substantial progress in improving the scientific understanding of the process of waste generation at the household level. Specifically the research has contributed the following points to the development of scientific knowledge:

(1) The household has been firmly established as the fundamental unit of waste generation (sections 2.12 and 6.7.3).

(2) In a cross section of households there is considerable variation in the quantity and composition of waste generated, to the extent that the average coefficient of variation for all waste categories is in excess of 150%.

(3) A relatively small fraction in the variation in total waste arisings is the result of random week to week differences in the waste arisings of a single household (the proportion of random week to week variation in total waste is 16%; for the individual component categories the average is 36.5%). This means that on balance most of the variation in waste arisings is 'systematic' amd can potentially be explained and predicted.

(4) The systematic variation in waste quantity and composition between households is attributable to the influence of a large number of different household characteristics. Of these, household size, stage in the Family Life Cycle, occupation of the household head and ownership of a deep freeze are among the principal characteristics associated with the generation of waste. Other household characteristics, most notably mode of newspaper purchase, type of domestic heating and domestic pet ownership, are related to specific categories of waste.

(5) Approximately a quarter of the variation in total waste arisings of individual households can be explained jointly in terms of the household characteristics considered in this research. This proportion is equivalent to approximately a third of the non-random element of variation in total waste arisings. The traditional UK method of waste estimation, the 'Higginson method', by contrast explains only 5% of the variation in the total

waste arisings of individual households (based on the same data set).

These findings represent both a contribution to knowledge in relation to household waste generation and also an advanced starting point for further research. Specifically, the findings provide information on the appropriate size of samples of households in waste surveys, as well as information on the factors which distinguish households in terms of waste arisings.

9.2.3 In addition to the analytical findings described above, a new method of area-based waste estimation was also developed as part of the research. The method responds to the practical needs encompassed in the second aim, and represents an improvement over the existing methods of waste estimation in current use in a number of respects:

(1) The method is geographically flexible and can be used to obtain estimates of waste arisings for any type of area based on the enumeration distinct 'building block'. The model is therefore aptly suited to the estimation of waste arisings from collection rounds, disposal catchments, areas within varying radii of plant locations and administrative or planning regions. Current methods of waste estimation which are based on less detailed or less geographically comprehensive data bases than the national census are not applicable at such high levels of resolution and do not possess the same geographical flexibility.

(2) The method provides a basis for waste forecasting by virtue of:

(a) its robustness

(b) being based on variables on which prospective data is available.

The Higginson method, by contrast, is based on 'surrogate' variables which are less likely to be stable over time, and on which the available data is less comprehensive.

(3) The method provides information on total waste and on 15 component categories of waste. This represents an improvement in detail over the methods in current use which specify only eight categories of waste.

(4) The method is more accurate than either the 'per capita method' or the '*Higginson method*'. The error ($p < 0.05$) associated with the predicted level of total waste arisings from 100 households is ± 157 kg estimated by the per capita method, ± 124 kg estimated by the Higginson method and 110 kg estimated by the waste arisings model developed in this research. Clearly these differences become still larger in absolute terms when scaled up over a greater number of households. Because no data is available it has not been possible to test empirically the model developed in this research against the other main competing approach which uses the statistical

technique of cluster analysis and the subsequent area sampling of waste arisings to calibrate each cluster. This approach constitutes the basis for the method developed by the Technical Institute of the University of Berlin (Goosmann 1980) and also the basis of the method recently advocated by Davies (1983). However, the critique of the underlying principles of this approach in Chapters 1 and 7 has shown that these methods essentially use cluster analysis to create a framework for stratified sampling. The 'area coefficients' obtained for each cluster are not related to individual household characteristics and shed no light on the reasons for variations in waste arisings and hence provide a poor scientific basis for sensitive, valid and reliable waste estimation.

(5) The method is cheap, simple and based on readily available data. All local authorities and universities in the UK have access to the census data stored on central filestore at regional computer centres. Estimates of waste arisings can therefore potentially be obtained for any area simply by combining the census data with the appropriate household waste generation coefficients on one computer 'run'. This procedure represents an improvement over the technique for grossing up involved in the Higginson method which required the computing by hand of subtotals of waste arisings in eight categories for each household type within a specified area.

9.3 Appraisal of the Research Method

9.3.1 This section makes a retrospective appraisal of the research as a process of scientific investigation. The discussion is organised in terms of an appraisal of the strengths of the research followed by an appraisal of its weaknesses.

9.3.2 The main strengths of the research lie in its thorough and detailed theoretical approach to the investigation of household waste generation, and in its rigorous empirical testing of the research hypotheses. As part of the theoretical phase of the research, concepts were borrowed from a number of other areas of study including marketing, behavioural science and economics. These were combined to develop a theoretical model of household waste generation. The theoretical phase of the research also included a detailed study of the structure and organisation of the waste management industry in Britain and the specific needs of each sector of the industry in relation to waste information. As a result of these studies, a new system for categorising household waste was devised which took account of both the origins of the component categories of household waste and the needs of the wastes industry.

9.3.3 The empirical phase of the research involved testing and calibrating the relationships between household characteristics and waste arisings on the basis of data collected in an extensive field survey of household characteristics and household waste. Hypothesis testing and model calibration were carried out using a number of different multivariate statistical methods both for statistical control and to investigate the basic constructs underlying the generation of household waste. As part of this process a set of synthetic composite variables were created using principal components analysis. These composite variables were then used as the basic elements in a regression analysis. This analytical technique has not, as far as is known, been previously applied in the context of waste modelling. The analytical phase of the research also involved the novel use of census data to obtain 'waste profiles' for urban neighbourhoods. Appendix C contains some illustrative examples of the features of different types of urban neighbourhood. The technique was made possible by the recent availability of census data on computer filestore at regional computer centres in the UK.

9.3.4 The main limitations of the research stem from the fact that it was only possible to examine one dimension of the variation in waste arisings. The household waste generation coefficients obtained were therefore specific to a single region and a single time period. The limited time and resources available for the research made it impractical to extend the research beyond these boundaries.

9.3.5 A further area of the research which viewed in retrospect could be upgraded in future work is in the selection and scaling of the explanatory and dependent variables used in the household waste model. The system of waste categorisation developed as part of the research was being tested for the first time and, although the categories were generally good at discriminating between waste from different origins, one category, 'scrap paper' was unsatisfactory in this respect. The waste in this category was found to originate from two fundametally different sources, firstly from food packaging plus 'kitchen towel' etc. and secondly from discarded mail, mailshots, stationery and other types of written communication. The findings of this research suggest that there would have been advantage in distinguishing between these two different types of waste, as the behavioural mechanisms through which they were generated were wholly different.

9.3.5 The results of the waste modelling exercise indicated that, in general, the set of explanatory variables selected were able to explain a higher proportion of the (non-random) variance in categories of post-consumer-related waste as distinct from categories of non-consumer waste. This reflects an intrinsic bias in the research towards the investigation of the link between the purchase of consumer goods and the process of waste generation. It is felt that this approach was justified for two reasons; firstly because of the high proportion of all household waste which consisted of consumer waste, and secondly because of the extensive body of empirical research available on the subject of purchasing behaviour. Nevertheless, it is possible that the overall performance of the household waste model could be improved by incorporating a larger number of variables related to the generation of non-consumer waste (e.g. 'garden size', location of the household with respect to civic amenity sites, bottle banks etc.), although it is unlikely that suitable estimates of these factors would be available for the purpose of area-based modelling.

9.4 Broader Perspectives and Future Directions

9.4.1 It is appropriate to round off this thesis by reference to the broader context out of which the research emerged, and to the future directions which the research may take. These issues are addressed successively in this section.

9.4.2 Chapter 1 described how the collection and disposal of household waste was once the epitome of a low technology industry, but at the same time how recent trends had transformed and upgraded both the status and the technology of the wastes industry. The research has contributed to the development of the field of waste management by providing a degree of scientific underpinning to the understanding of household waste generation and also an improved method of area estimation of waste arisings. The research is particularly timely since it coincides with a rapid expansion of the information industry, as a result of which a new wealth of socio-economic, demographic and marketing information is becoming available on computer databases. This means that such information can now be accessed and processed more easily and at higher levels of resolution than was previously possible, with consequent benefits for the estimation of waste arisings.

9.4.3 There is a great deal of potential for further work in this field of research. The need for further development in a number of areas has already been established in Chapter 8. These areas are:

(1) The development of a 'seasonal dimension' to the model. This would involve further analysis of household waste at intervals throughout the year, though it would not be necessary to carry out sampling on the same scale as in the original field survey.

(2) The development of a 'regional dimension'. This would involve addressing experimentally a number of questions including how well the model transferred to other urban areas; how well it transferred to rural areas; and whether an established system of area classification could be used as a basis for predicting changes in the household waste generation coefficients.

(3) The development of a forecasting capability. This would involve testing the stability of the model components and the parameters of the components over time. There is also potential for incorporating data from market forecasting, together with data on planned developments within the packaging and processing industries into a sophisticated waste forecasting model.

Other areas for potential future development include:

(1) The further validation of the area-based model through the sampling of batches of household waste from selected areas and by the subsequent comparison of observed and expected results.

(2) The investigation of the possibility of interfacing the waste arisings model with computer-based methods for the design of rounds for waste collection vehicles. The implications of variations in waste quantity and composition for vehicle round design have been discussed in Chapter 3. A number of computing software systems such as 'ROSS' and 'EUROBIN' have recently become available to assist local authorities with the management of refuse collection (Jackson 1983). These subdivide collection areas into discrete units of work. The workload associated with each unit is currently determined by the programmes using conventional methods of waste estimation, and hence the results are subject to the limitations associated with these methods. The application of the waste arisings model in this context represents an example of how the research can contribute directly to a practical aspect of waste management.

(3) The determination of household waste quantity and composition as a national scale at a regional level of aggregation. A comprehensive, national picture of

waste arisings on a region-by-region basis has a great variety of potential applications in the contexts of waste management and planning. These include:

(a) The evaluation of waste abatement strategies advocated by national government or by the EEC (e.g. the recent EEC-proposed controls on the re-use of beverage containers (Nicholson-Lord 1981).

(b) The appraisal of the economic potential for the recycling of household waste on a national scale, and the evaluation of the case for a national recovery programme.

(c) The estimation of waste arisings within the regional boundaries of waste disposal authorities. This is important both from a practical waste management perspective and also to meet the requirements of the Control of Pollution Act 1974 which requires each WDA to prepare a comprehensive waste disposal plan containing, amongst other information, details of the types of waste arising within its area.

(4) An investigation of the extent to which the modelling approach can be extended internationally. For this purpose it would be instructive to test the model developed in this research on the data collected by GENDAN in Denmark (see section 1.3.6).

(5) Going beyond the development of a model that deals specifically with household waste there is a related subject area in which the modelling approach could be usefully applied, namely the estimation of commercial waste arisings. Commercial waste is closely associated with household waste, to the extent that in some areas the two are collected simultaneously by the same local authority collection service. The estimation of commcercial waste arisings is therefore of considerable interest to local authorities in order to determine:

(a) the quantity and composition of commercial waste which is mixed with household waste.

(b) the quantity and composition of commercial waste not removed by the regular household collection service, but which local authorities nevertheless have a duty to collect and to levy a charge for collecting.

9.4.4 These areas represent themes for follow-up work aimed at both complementing the findings of this research and at extending the scientific investigation of waste arisings.

APPENDIX A

Method of Waste Collection and Analysis

A 1. Introduction

This Appendix describes in detail the various stages in the collection, sorting, identification and classification of waste arisings. It provides a complete description of the types of material which comprise the 15 categories of household waste. The sources of error inherent in the process of waste analysis are described, and an account is given of the procedure used to determine the size of the error. As a means of justifying the innovative approach to waste analysis used in this research, a critique is given in the first section of this appendix of the conventional method of waste analysis which is used as a basis for the estimation of household waste arisings in the UK.

A 1.1 Critique of the 'Standard' Approach to Waste Analysis

Previous surveys of household waste carried out in the UK (e.g. Birch 1976, Ling 1976, Merseyside 1981) have almost universally adopted the standard 'Higginson'/DoE approach to waste analysis (see section 1.3.5) first devised in 1935 and subsequently updated in 1965 and again in 1982. This method recommends that household waste is collected by the normal collection procedure (which frequently involves power compression) and analysed in bulk. The suggested analysis procedure involves first passing waste over a square mesh griddle and then separating all materials on the griddle into eight classes. The use of a mechanical screening device is recommended to improve working conditions and to reduce costs.

The method described above is subject to a number of criticisms. Firstly there is no stipulation as to whether waste should be analysed 'as discarded' (i.e. no loose state) or after compaction. Compaction alters the characteristics of waste, resulting in the breakdown of fragile materials, redistribution of fine substances, and the migration of moisture between classes of waste material (Niessen and Chansky 1970). The second criticism of the traditional approach is that the use of a mechanical screen tends to swell the fines category by breaking down friable material into smaller particles. Thirdly, although it is suggested that a full week's waste is collected from households, allowance is made by the method for the scaling up of a waste sample based on part of a week. Implicit in this procedure is the assumption that households produce equal types and amounts of waste on each week-day when in fact it is more likely that patterns of waste generation will vary during the week, reflecting the household's weekly routine. The fourth criticism is that the 'standard eight' waste categories are not comprehensively defined and are subject to differences in interpretation.

Because of these criticisms of the conventional method and because of the departure in this research from the use of the standard eight waste categories, a new approach to waste analysis was devised. This is described in detail below.

A 2. Collection Procedure

The procedure for waste collection was carefully devised in order to obtain samples which were representative of households' normal weekly production of waste arisings. The waste samples were collected on the normal collection day either shortly before or shortly after the normal collection time. The procedure involved close co-operation with the regular collection services to achieve the necessary synchronisation of collection schedules. On certain collection rounds the drivers of refuse collection vehicles carried lists of the households from which the dustbins were required for survey purposes and these dustbins were left out of the regular collection, to be removed later. Although each of the households included in the survey had previously agreed to participate, none were aware in which week their waste would be analysed. By adopting this approach it was hoped to avoid any abnormal or irregular disposal behaviour.

Waste from each household was labelled with a computer-produced coded tag and transported to a central sorting area. Only waste material contained in dustbins or dustbin liners or refuse sacks was removed for analysis. Other unbagged items left near the dustbin (e.g. rolls of carpet, bicycle frames, builders waste) were not removed. A slightly different procedure was adopted for the collection of waste from households which were equipped with communal disposal facilities (e.g. skips, chutes and palladins). In these circumstances refuse sacks were delivered to each household and householders were asked to save there reduse for a week, at the end of which time the waste was taken for analysis. It is recognised that samples collected in this way may have been subject to bias, for two reasons:

(1) Only those households who were able and willing to co-operate with the slightly unusual request to save a week's waste were included in the sample.

(2) The knowledge that the waste being saved was intended for imminent analysis may have caused households to 'vet' the articles being disposed of.

Despite these limitations however, it was considered that the approach adopted was preferable to the exclusion altogether from the sample of those households which were not equipped with individual dustbins.

A 3. Waste Analysis Procedure

Waste samples were analysed soon after collection to avoid problems of decay, migration of moisture between classes of waste material, and hatching of fly lavae. The waste was sorted on purpose-built static screens with two operators working at each screen. The procedure for the separation, classification and weighing of waste articles is illustrated diagramatically in Figure A 1. The total weight of waste was obtained first by weighing the bagged sample from each household using a spring balance. The waste was then emptied onto a 2cm mesh screen from which the different waste components were handpicked into buckets. Hand magnets were used to test the metallic properties of certain items. Fine substances which passed through the screen were collected on ground sheets. The component categories were weighed on spring balances graduated in divisions of 10 grammes. The balances had been previously zeroed to the weight of the buckets to allow the weight of waste to be read directly. The weights of each category of waste and the total weight of waste were recorded on pre-coded sheets together with a code identifying the household. The following sections describe the fifteen waste categories in detail. A sequence of photographs illustrating the typical contents of each of the waste categories is shown in Plates A.1 to A.15.

(1) Organic Kitchen Waste

This category comprised all organic materials arising from the preparation of food, together with edible leftovers from meals eaten by the household. The largest proportion of this category was made up of

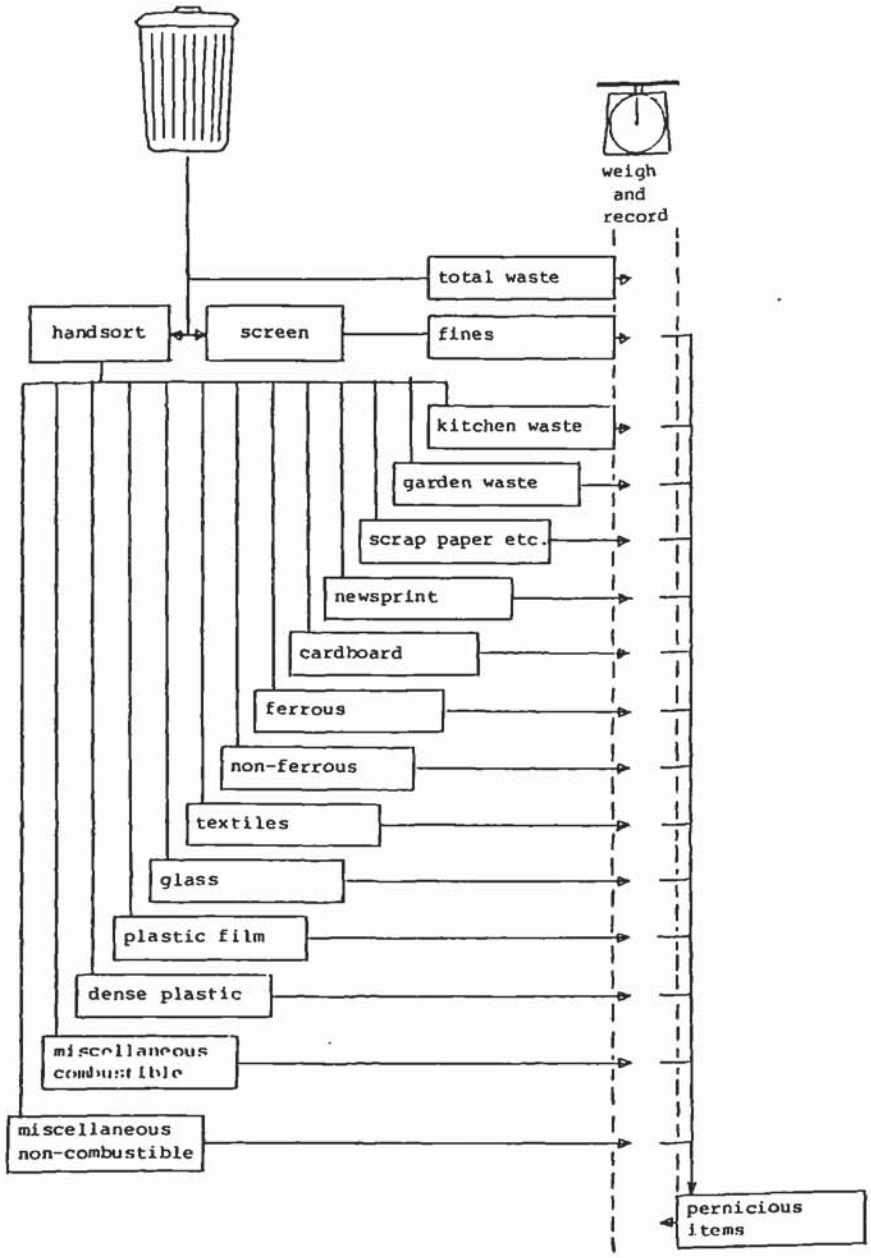

Fig. A.1 Schematic diagram of the waste analysis procedure peelings, rind and bones and food that had become tainted or started to decay. The analysis of food leftovers proved to be one of the most difficult and unpleasant tasks during sorting since this type of waste was frequently wrapped in paper or plastic and required painstaking separation. An indication of the relative proportions of different types of kitchen waste encountered is given in Table A.1 below.

TYPE OF KITCHEN WASTE	APPROXIMATE % BY WEIGHT
Edible food leftovers	40
Peelings, rind, leaves from vegetables	50
Eggshells, inedible trimmings, bones from meat and fish	10

Table A.1 Main Constituents of Organic Kitchen Waste

(2) Organic Garden Waste

This category consisted of all non-food vegetable matter including grass and hedge clippings, weeds, tree prunings and dead flowers or houseplants. Although the policy of Birmingham refuse collection authority precluded the removal of garden waste, a large quantity of this type of material was nevertheless found amongst the contents of Birmingham's dustbins.

(3) Paper Packaging and Other Scrap

Classified under this heading were all types of paper packaging such as paper bags and wrappers, together with discarded cosmetic and sanitary paper and waste stationery. Most of the waste included in this category derived from food packaging with a large contribution from 'kitchen towel' and tissues.

(4) Newsprint

The 'newsprint' category included all forms of newspapers, magazines, periodicals, directories, catalogues and books. Daily newspapers were the predominant source of this type of waste. In many cases the newspaper had been used first to wrap semi-solid or odourous wastes or to soak up spilled substances such as paint or oil. As a result the paper was frequently contaminated and slightly heavier than in its 'clean' form. Other types of newsprint such as discarded books and periodicals were a less important source of newsprint although where they did occur, they generally added substantially to the weight of this category.

(5) Cardboard

Cardboard wste derived primarily from cardboard outercases used for food packaging, and cardboard tubes from rolls of sanitary paper. Other sources of waste cardboard included shirt-backing, and cardboard cartons and wadding from electrical goods and childrens toys. Large cardboard packing cases from domestic appliances such as refrigerators and washing machines also contributed to this category.

(6) Ferrous Metals

Ferrous metals occurred mainly in the form of food tins made from tin-plated steel. Discarded aerosol cans were also a substantial source of ferrous metals. Among other ferrous items found were pieces of steel cutlery, car components and discarded tools and garden implements.

(7) Non-Ferrous Metals

The most common types of item in this category were foil caps and closures, foil baking trays and aluminium beverage cans. Less frequently encountered were aluminium cooking utensils and vaccuum cleaner parts. A complete aluminium cylinder head was found on one occasion. Examples of non-white, non-ferrous metals were very rare.

(8) Textiles

This category comprised all types of fabric-based products including discarded clothing, household fabrics such as curtains and bedding, carpet offcuts, sack-cloth and rag. Synthetic textiles were classified under this heading provided that they were woven. A relatively new type of item which also qualified as a 'textile' was the disposable diaper. Like newspapers, textiles were frequently 'contaminated' having been used in the form of rag for some secondary purpose before disposal.

(9) Glass

Only glass which originated from packaging of food and beverages was included in this cateogry. Discarded wine and beer bottles were the predominant source of glass, in both whole and broken (cullet) form. Additional glass occured in the form of food jars (e.g. of a type which had contained ketchups or preserves and milk bottles. A small proportion of glass derived from general household items such as kitchenware, ornaments, light fittings, broken windows etc.

(10) Plastic Film

This category covered a range of different types of plastic polymer including low density polythene (LDPE), PVC and cellophane. Most occurred in the form of food packaging (e.g. food bags and 'cling wrap'), plastic carrier bags and bin liners and protective sheet used in the packaging of electrical appliances, car seats etc.

(11) Dense Plastics

Dense plastics occured in a variety of different forms including high density polyethylene (HDPE), polystyrene, polypropylene, 'ABS' (acrylonitrite butadiene styrene) and thermosetting plastics. Discarded items made from these materials were typically either containers from household products such as detergents and non-solvent cleaning fluids, or else containers or dispensers from personal care items such as shampoos or cosmetics. Other types of dense plastic items included combs, buttons, knitting needles, broken credit cards and records.

(12) Miscellaneous Combustible

Waste items were allocated to this category either because they were made from some unclassified combustible material (e.g. rubber or wood) or because they were comprised of mixtures of combustible materials (e.g. plasticised cardboard) or, occasionally because their precise composition was uncertain but evidently combustible. Typical examples of miscellaneous combustible items were timber offcuts, articles of basketwork and discarded footwear.

(13) Miscellaneous Non-Combustible

This category effectively served as a 'dump' for items which could not be properly allocated to any other category in the classification scheme. A large proportion of this type of waste originated from gardening and DIY work. The main constituents were rubble and stones, spent bags of plaster and cement, glass tableware and broken window panes, crockery and flowerpots.

(14) 'Fines <2cm'

All materials which passed through the 2cm mesh used for screening the waste were classified under this heading. 'Fines' consisted largely of ash, garden soil, carpet sweepings and vacuumings, cigarette stubs and small-sized organic material.

(15) Pernicious Items

'Pernicious items' were defined as those which were plainly toxic or otherwise harmful or else which were likely to pose a problem on disposal, either by degrading into a toxic or harmful form or by damaging or impeding the disposal process itself. These types of items were unusual but were nevertheless found to be present in household waste in measurable quantities. Examples included insecticides, paints and solvents, pharmaceutical products, medical and veterinary wastes (several hundredweights of this type of waste were removed from one property surveyed during the research) and types of product which were known to have a detrimental effect on separation equipment (e.g. rolls of plastic banding wire and electrical cable).

4. Determination of Measurement Error

Inevitably there ere some practical difficulties during the handsorting of waste. The most common problems were:

(1) Loss of materials, especially particulate substances such as dust and ash together with liquids or semi-liquids which tended to adhere to screens and containers.

(2) Classification of ambiguous items, particularly laminates and compound items.

(3) Physical separation of mixtures of materials such as assemblies of components or else fine or coagulant substances which were too thoroughly blended to allow complete separation.

(4) Instrument error and operator error in the reading of weighing scales.

A further potential source of error which is sometimes referred to in monographs on waste analysis and estimation (e.g. Higginson 1965, Merseyside County Council 1981) is the assimilation of moisture by household waste during periods of rainfall. All waste samples collected during this research had been stored in plastic refuse sacks which acted as an effective barrier to moisture. In a small number of cases, where holes in dustbin lids or tears in plastic sacks had exposed the waste contents to rain, the affected samples were discarded.

A small scale experimental exercise was set up to determine the extent of the various forms of measurement error. This involved the repeat sorting of the same batch of waste samples by different teams of operators. In total, ten samples of waste were analysed by four separate teams of operators. The discrepancies in the findings of each team indicated the extent of measurement error. The results of the separate analyses on three different types of waste (kitchen waste, paper and plastic film) are shown in Tables

A.2 and A.3. The interpretation of these results and the implications of measurement error have been discussed in sections 5.56 to 5.57 in the main text of the thesis.

Table A.2 Results of the Analysis of Ten Batches of Kitchen Waste by Separate Teams of Operators

Operator Team	Measured Level of Waste (kg)										
	BATCH 1	BATCH 2	BATCH 3	BATCH 4	BATCH 5	BATCH 6	BATCH 7	BATCH 8	BATCH 9	BATCH 10	
Operator Team 1	0.62	2.62	0.32	2.24	3.98	0.74	1.60	1.78	2.51	2.20	
Operator Team 2	0.88	2.18	0.23	2.18	3.88	0.74	1.42	1.76	2.46	2.20	
Operator Team 3	0.84	2.04	0.32	2.17	3.84	0.62	1.55	1.62	2.37	2.20	
Operator Team 4	0.68	2.12	0.30	2.14	2.90	0.72	1.66	1.54	2.18	2.20	
Mean $\bar{x}$	0.76	2.15	0.29	2.18	3.65	0.71	1.56	1.68	2.38	2.20	Pooled Variance σ^2/n
Variance σ^2	0.0117	0.0065	0.0014	0.0013	0.1901	0.0025	0.0078	0.0010	0.0159	0	0.0238

Table A.3 Results of the Analysis of Ten Batches of Waste Glass by Separate Teams of Operators

Operator Team	Measured Level of Waste (kg)										
	BATCH 1	BATCH 2	BATCH 3	BATCH 4	BATCH 5	BATCH 6	BATCH 7	BATCH 8	BATCH 9	BATCH 10	
Operator Team 1	0.30	0.08	0.16	0.10	1.20	0.02	0.30	0.38	1.06	0.00	
Operator Team 2	0.32	0.08	0.72	0.14	1.17	0.02	0.10	0.24	0.98	0.00	
Operator Team 3	0.30	0.10	0.64	0.14	0.98	0.00	0.10	0.36	1.02	0.00	
Operator Team 4	0.31	0.08	0.60	0.18	0.94	0.00	0.10	0.36	1.06	0.00	
Mean $\bar{x}$	0.31	0.09	0.53	0.14	1.07	0.01	0.15	0.34	1.03	0.00	Pooled Variance σ^2/n
Variance σ^2	0.0001	0.0001	0.0475	0.0008	0.0130	0.0001	0.0075	0.0031	0.0011	0.00	0.0073

Plate A.1 Kitchen Waste

Plate A.2 Garden Waste

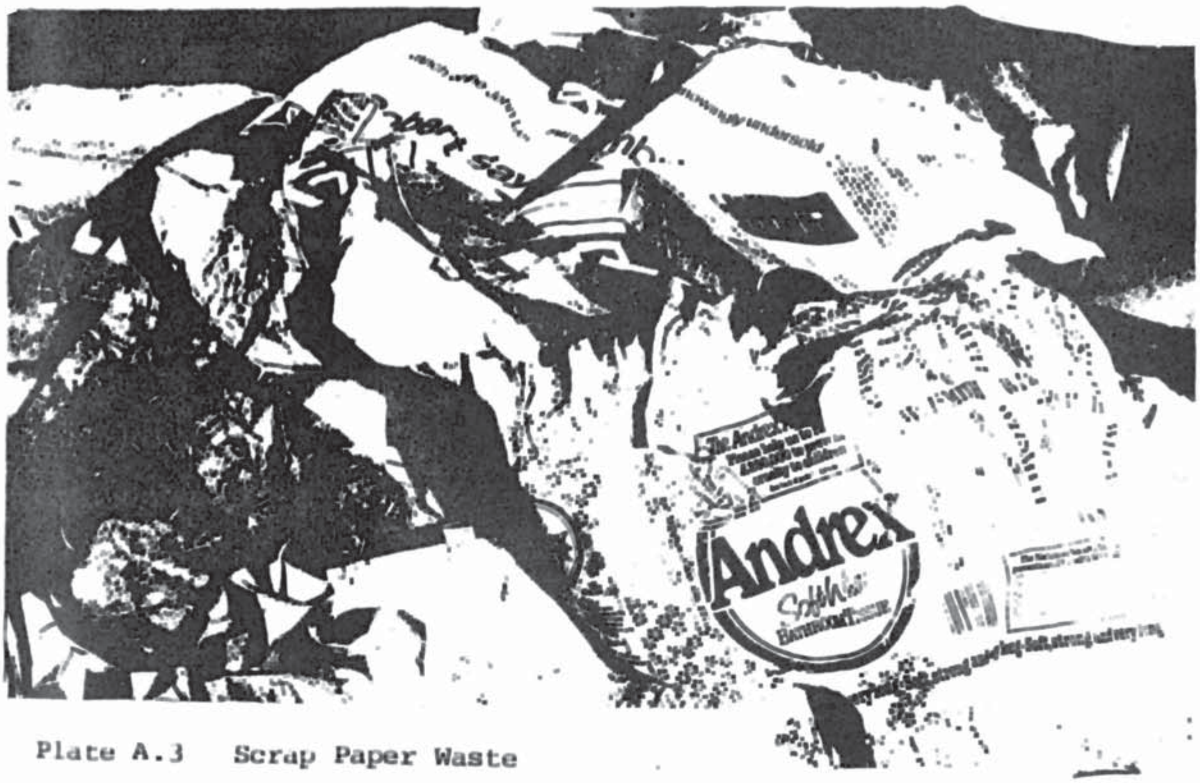

Plate A.3 Scrap Paper Waste

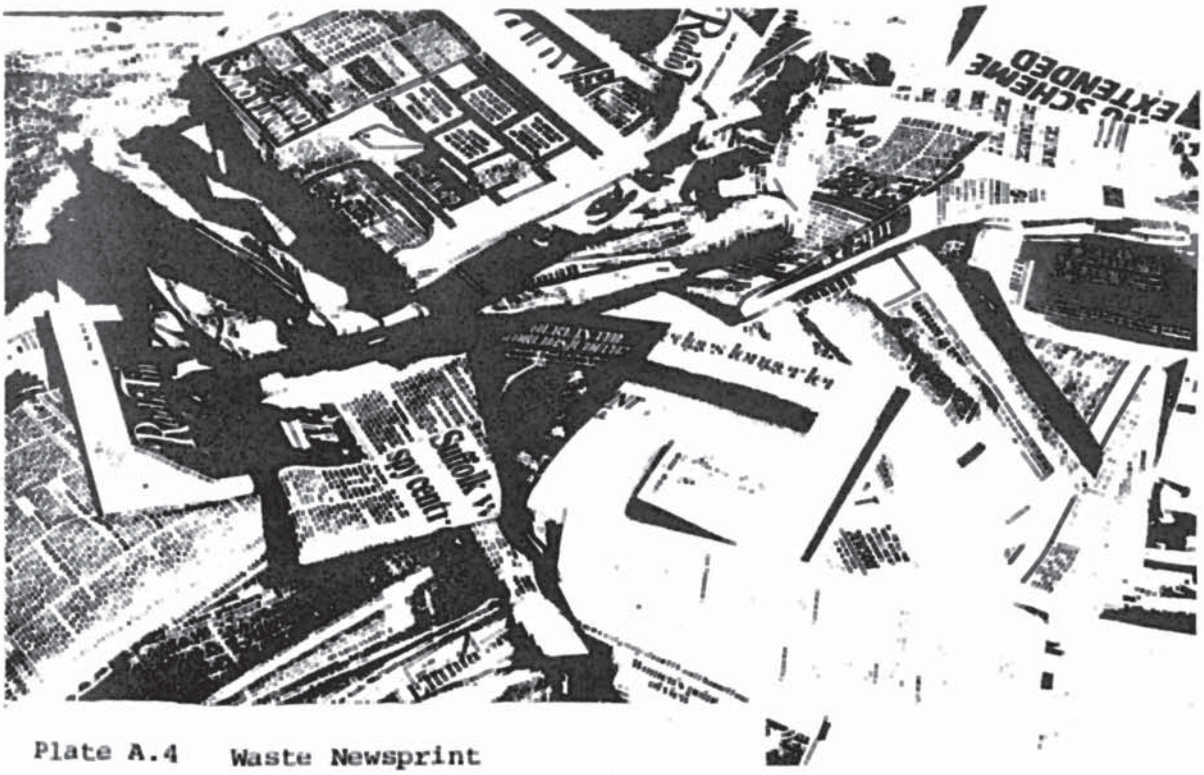

Plate A.4 Waste Newsprint

Plate A.5 Waste Cardboard

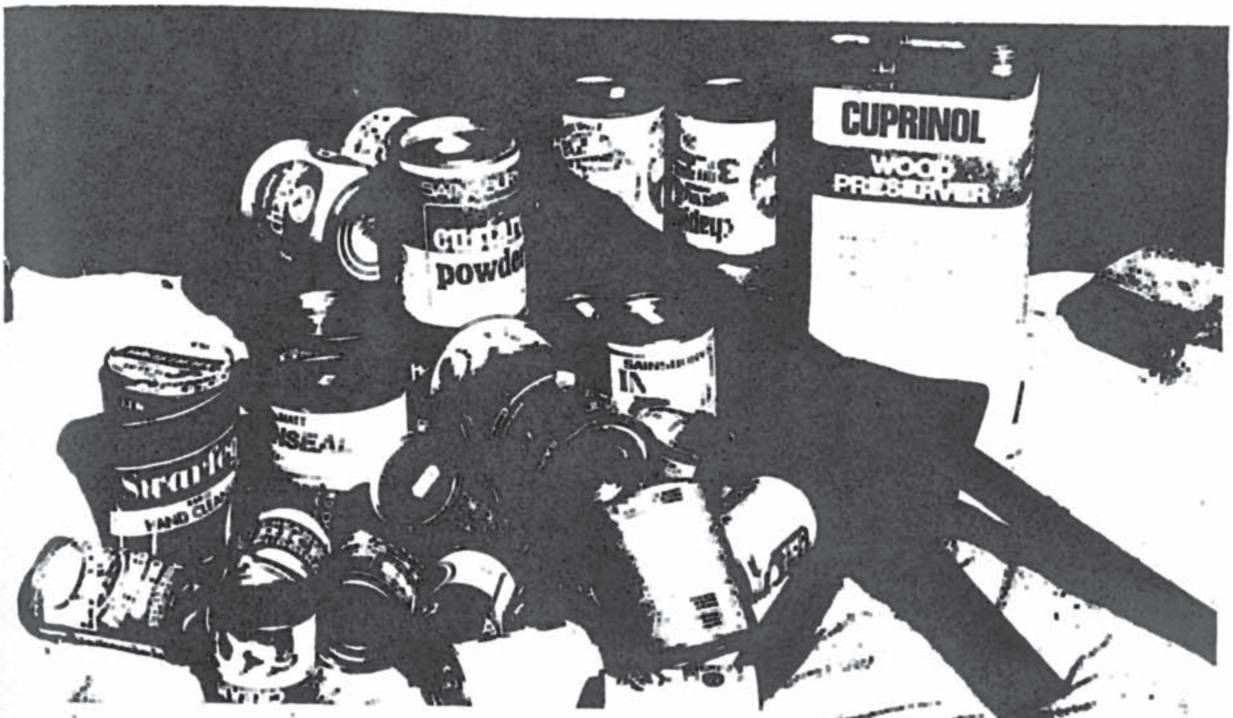

Plate A.6 Ferrous Waste

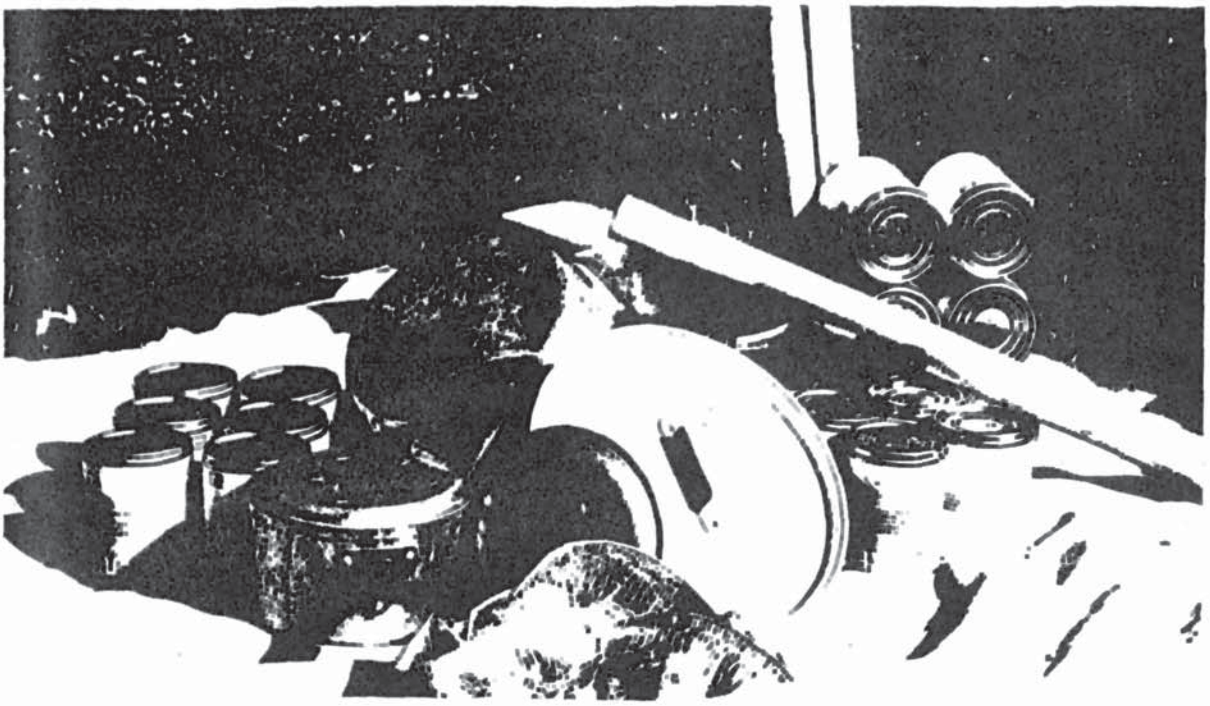

Plate A.7 Non-Ferrous Waste

Plate A.8 Waste Glass

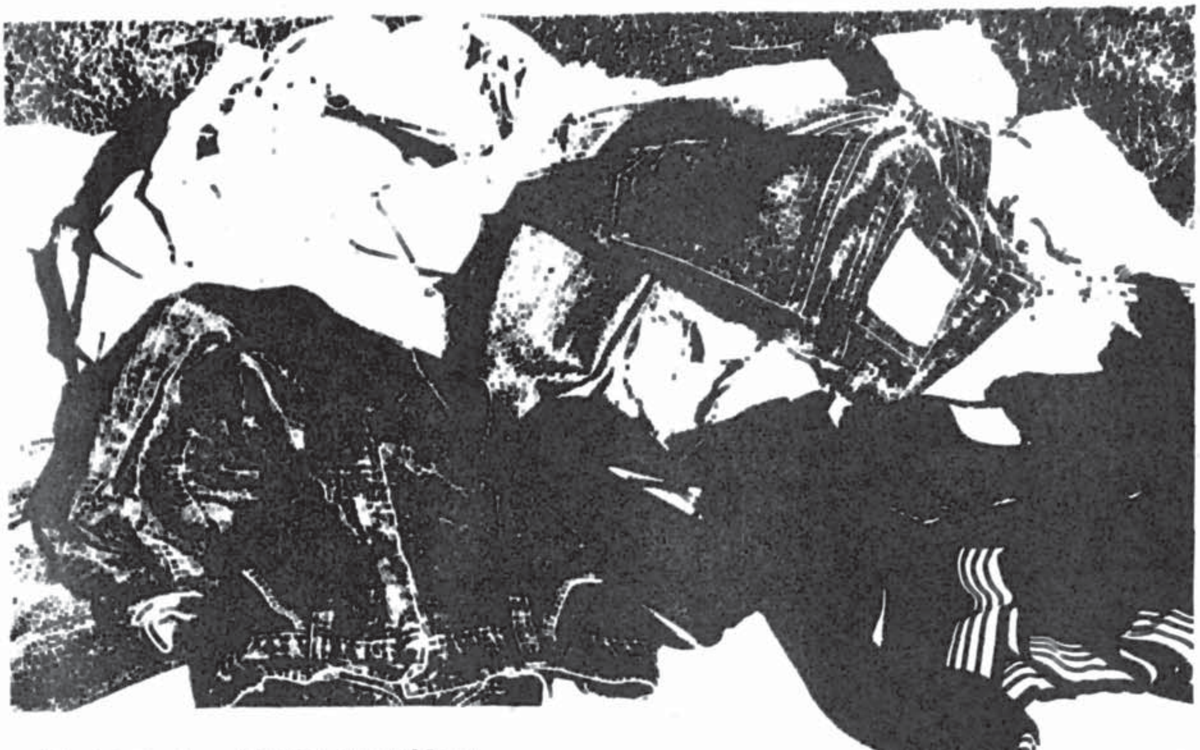

Plate A.9 Waste Textiles

Plate A.10 Plastic Film Waste

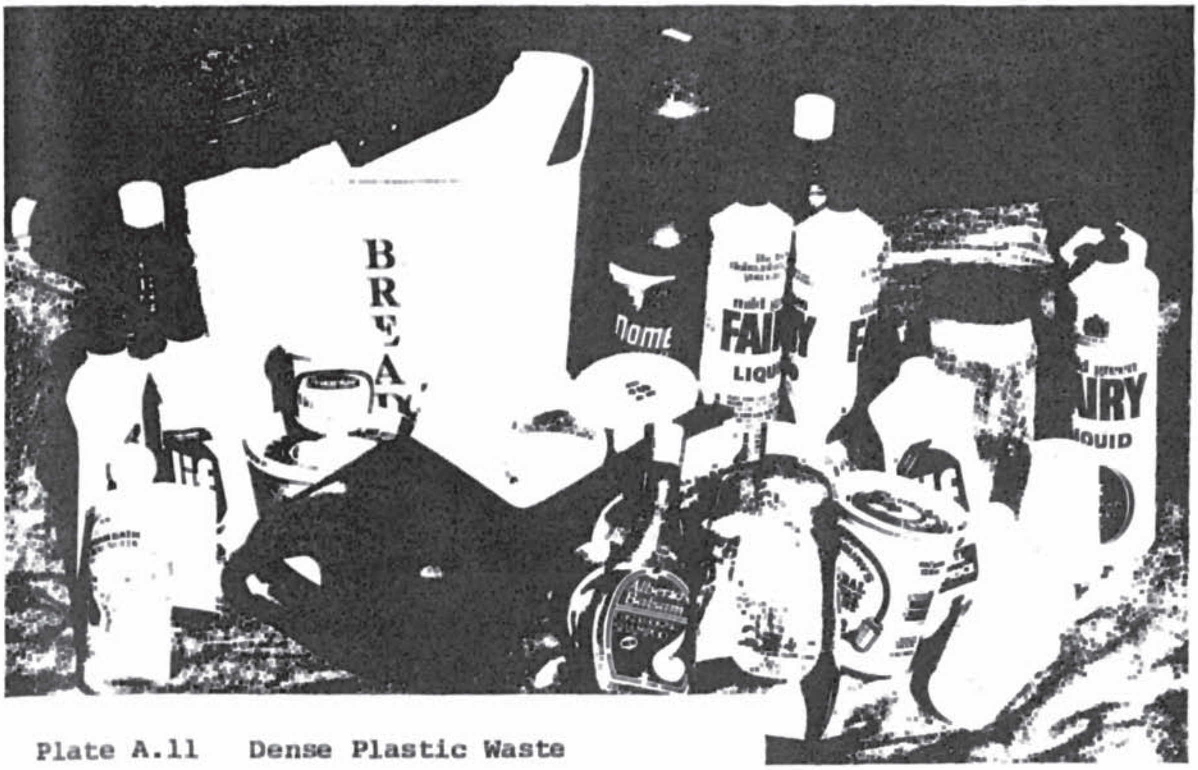

Plate A.11 Dense Plastic Waste

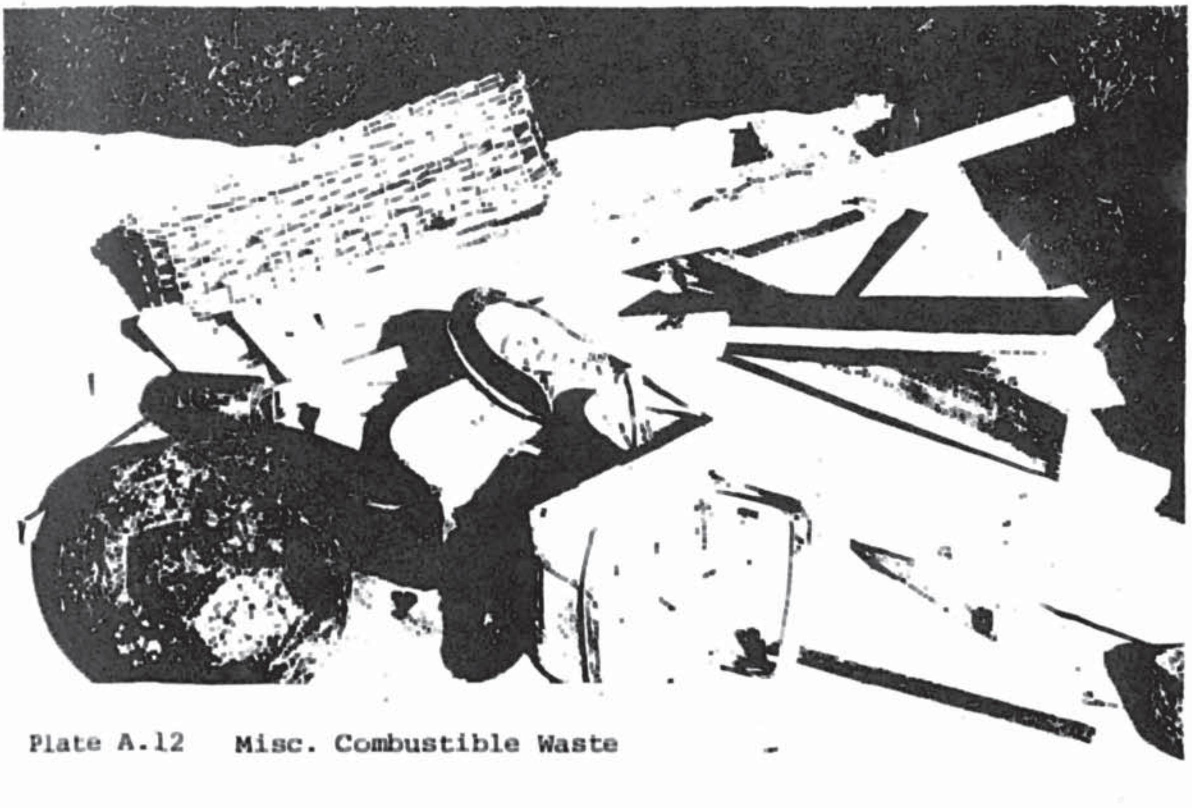

Plate A.12 Misc. Combustible Waste

Plate A.13 Misc. Non-Combustible Waste

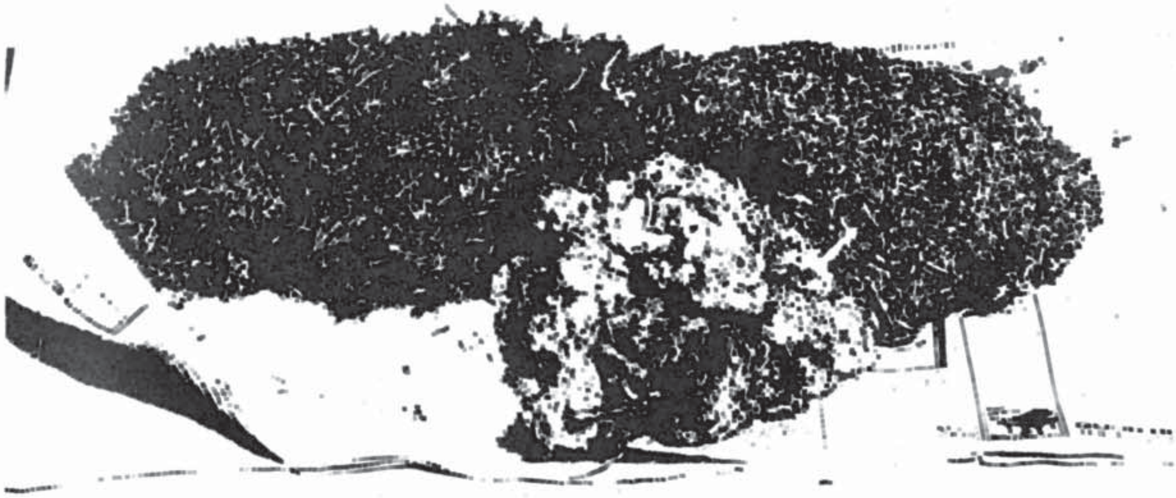

Plate A.14 Fines < 2cm.

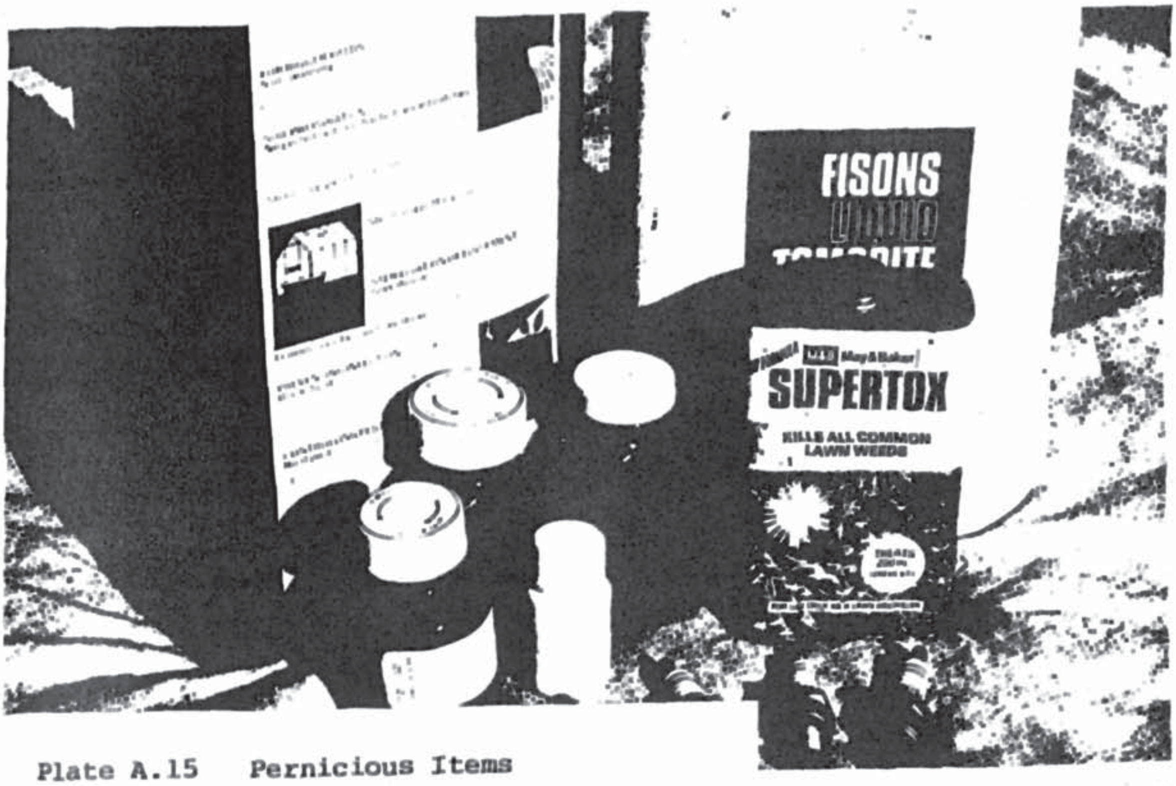

Plate A.15 Pernicious Items

APPENDIX B

STATISTICAL SUMMARY OF THE RESULTS OF THE HOUSEHOLD WASTE SURVEY

This Appendix describes statistically and graphically the results of the household waste survey carried out as part of this research.

The statistical parameters of the distributions of the various measurements of household waste are summarised in Tables B.1 to B.4 as follows:

(1) Table B.1: Statistical parameters of the distributions of household waste expressed in kg/hh/wk.

(2) Table B.2: Statistical parameters of the distributions of measurements of household waste expressd in percentage weight.

(3) Table B.3: Statistical parameters of the distributions of measurements of household waste expressed in kg/hh/wk.

(4) Table B.4: Statistical parameters of the distributions of measurements of the average week-to-week differences in waste arisings from individual hosueholds (kg/hh/wk).

The distributions of the various measurements of household waste are also illustrated in a series of computer drawn graphs (Figures B.1 to B47) as follows:

(1) Figures B.1 to B.16: Distributions of the categories of household waste expressed in kg/hh/wk.

(2) Figures B.17 to B.31: Distributions of the categories of household waste expressed in percentage weight.

(3) Figures B.32 to B.47: Distributions of the average week-to-week differences in waste arisings from individual households (kg/hh/wk).

Table B.1 Statistical Parameters of the Distributions of Household Waste Expressed in Absolute Weight n = 1277

WASTE CATEGORY	Mean $\bar{x}$ kg/hh/wk	Minimum kg/hh/wk	Maximum kg/hh/wk	Range kg/hh/wk	Standard Deviation σ kg/hh/wk	Variance σ^2 kg/hh/wk	Coefficient of Variance CV%
Total Waste	10.11	0.00	54.10	54.10	6.48	42.00	64.1
Kitchen Waste	3.18	0.00	24.90	24.90	2.69	7.25	84.6
Garden Waste	0.65	0.00	20.90	20.90	1.84	3.37	283.1
Scrap Paper etc	0.70	0.00	10.06	10.06	0.74	0.55	105.7
Newsprint	1.24	0.00	13.00	13.00	1.42	2.02	114.5
Cardboard	0.54	0.00	8.90	8.90	0.61	0.37	113.0
Ferrous	0.60	0.00	6.70	6.70	0.61	0.38	101.7
Non-Ferrous	0.08	0.00	2.46	2.46	0.17	0.03	212.5
Textiles	0.31	0.00	19.60	19.60	0.98	0.96	316.1
Glass	0.97	0.00	11.32	11.32	1.30	1.69	134.0
Plastic Film	0.27	0.00	2.40	2.40	0.24	0.06	88.9
Dense Plastic	0.23	0.00	6.90	6.90	0.34	0.12	147.8
Misc. Combustible	0.60	0.00	12.40	12.40	1.29	1.67	215.0
Misc. Non-combustible	0.23	0.00	12.52	12.52	0.82	0.67	356.5
Fines	0.45	0.00	17.00	17.00	1.01	1.02	224.4

B.2 Statistical Parameters of the Distributions of Household Waste Expressed as Percentages of Total Waste n = 1277

WASTE CATEGORY	Mean $\bar{x}$ %	Minimum %	Maximum %	Range %	Standard Deviation σ %	Variance σ^2 %	Coefficient of Variance CV%
Total Waste							
Kitchen Waste	31.66	0.00	93.09	93.09	17.26	297.92	54.5
Garden Waste	6.08	0.00	100.00	100.00	14.28	203.88	234.9
Scrap Paper etc	7.31	0.00	55.19	55.19	5.75	33.09	78.7
Newsprint	12.81	0.00	76.11	76.11	12.50	156.28	97.6
Cardboard	5.54	0.00	50.00	50.00	4.57	20.90	82.5
Ferrous	6.42	0.00	57.63	57.63	5.94	35.23	92.5
Non-Ferrous	0.80	0.00	26.19	26.19	1.84	3.40	230.0
Textiles	2.61	0.00	77.25	77.25	6.27	39.32	240.2
Glass	9.43	0.00	81.95	81.95	10.56	111.60	112.0
Plastic Film	3.08	0.00	100.00	100.00	4.49	20.12	145.8
Dense Plastic	2.35	0.00	43.29	43.29	2.65	7.02	112.8
Misc. Combustible	5.01	0.00	95.79	95.79	9.53	90.78	190.2
Misc. Non-combustible	1.90	0.00	74.66	74.66	5.92	35.10	311.6
Fines	4.15	0.00	66.29	66.29	6.41	41.09	154.5

B.3 Statistical Parameters of the Distributions of Per Capita Levels of Waste Arisings n = 1277

WASTE CATEGORY	Mean $\bar{x}$ kg/hh/wk	Minimum kg/hh/wk	Maximum kg/hh/wk	Range kg/hh/wk	Standard Deviation σ kg/hh/wk	Variance σ^2 kg/hh/wk	Coefficient of Variance CV%
Total Waste	3.93	0.00	26.30	26.30	2.74	7.53	69.7
Kitchen Waste	1.21	0.00	12.20	12.20	1.11	1.23	91.7
Garden Waste	0.30	0.00	11.90	11.90	0.92	0.85	306.7
Scrap Paper etc	0.26	0.00	2.50	2.50	0.26	0.07	100.0
Newsprint	0.51	0.00	6.35	6.35	0.62	0.38	121.6
Cardboard	0.20	0.00	2.23	2.23	0.20	0.04	100.0
Ferrous	0.24	0.00	3.35	3.35	0.28	0.08	116.7
Non-Ferrous	0.03	0.00	1.23	1.23	0.07	0.00	233.3
Textiles	0.11	0.00	4.64	4.64	0.32	0.10	290.9
Glass	0.38	0.00	4.76	4.76	0.54	0.29	142.1
Plastic Film	0.10	0.00	1.20	1.20	0.10	0.01	100.0
Dense Plastic	0.09	0.00	3.45	3.45	0.15	0.02	166.7
Misc. Combustible	0.23	0.00	10.25	10.25	0.61	0.37	265.2
Misc. Non-combustible	0.09	0.00	10.70	10.70	0.46	0.21	511.1
Fines	0.18	0.00	8.50	8.50	0.47	0.22	261.1

B.4 Statistical Parameters of the Distributions of the Average Week-to-Week Differences in Household Waste n = 73

WASTE CATEGORY	Mean $\bar{x}$ kg/hh/wk	Minimum kg/hh/wk	Maximum kg/hh/wk	Range kg/hh/wk	Standard Deviation σ kg/hh/wk	Variance σ^2 kg/hh/wk	Coefficient of Variance CV%
Total Waste	2.82	0.20	16.33	16.13	2.60	6.76	92.2
Kitchen Waste	1.45	0.05	6.89	6.84	1.39	1.94	95.9
Garden Waste	0.67	0.00	7.63	7.63	1.24	1.54	185.1
Scrap Paper etc	0.39	0.03	1.52	1.49	0.30	0.09	76.9
Newsprint	0.82	0.04	4.46	4.42	0.81	0.65	98.8
Cardboard	0.37	0.01	2.10	2.09	0.33	0.11	89.2
Ferrous	0.36	0.01	1.31	1.30	0.30	0.09	83.3
Non-Ferrous	0.07	0.00	0.56	0.56	0.10	0.01	142.9
Textiles	0.42	0.00	3.42	3.42	0.58	0.34	138.1
Glass	0.75	0.03	3.21	3.18	0.68	0.46	90.7
Plastic Film	0.15	0.02	0.78	0.77	0.15	0.02	100.0
Dense Plastic	0.14	0.00	0.62	0.62	0.12	0.01	85.7
Misc. Combustible	0.52	0.00	8.30	8.30	1.17	1.37	225.0
Misc. Non-combustible	0.30	0.00	3.94	3.94	0.58	0.34	193.3
Fines	0.31	0.01	3.04	3.03	0.44	0.20	141.9

Fig. B.1 Frequency distribution of total waste arisings (kg/hh/wk)

```
EACH * REPRESENTS  1Ø OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     Ø         78     ********
     5        434     ********************************************
    1Ø        418     ******************************************
    15        2Ø2     *********************
    2Ø         89     *********
    25         32     ****
    3Ø         11     **
    35          5     *
    4Ø          4     *
    45          2     *
    5Ø          1     *
    55          1     *
```

Fig. B.2 Frequency distribution of kitchen waste (kg/hh/wk)
EACH * REPRESENTS 1Ø OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	253	**************************
2	482	***
4	29Ø	*****************************
6	139	**************
8	65	*******
1Ø	24	***
12	14	**
14	6	*
16	2	*
18	1	*
2Ø	Ø	
22	Ø	
24	1	*

Fig. B.3 Frequency distribution of garden waste (kg/hh/wk)
EACH * REPRESENTS 25 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	1Ø81	**
2	117	*****
4	38	**
6	18	*
8	5	*
1Ø	5	*
12	7	*
14	4	*
16	1	*
18	Ø	
2Ø	1	*

Fig. B.4 Frequency distribution of scrap paper waste (kg/hh/wk)

```
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
      0      619      ******************************************
      1      541      *************************************
      2       88      ******
      3       19      **
      4        4      *
      5        2      *
      6        2      *
      7        0
      8        0
      9        1      *
     10        1      *
```

Fig. B.5 Frequency distribution of waste newsprint (kg/hh/wk)

```
EACH * REPRESENTS  10 OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
      0      447      *********************************************
      1      454      **********************************************
      2      215      **********************
      3       84      *********
      4       33      ****
      5       18      **
      6       13      **
      7        3      *
      8        2      *
      9        3      *
     10        1      *
     11        3      *
     12        0
     13        1      *
```

Fig. B.6 Frequency distribution of waste cardboard (kg/hh/wk)
EACH * REPRESENTS 2Ø OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	769	***************************************
1	445	***********************
2	5Ø	***
3	6	*
4	4	*
5	1	*
6	Ø	
7	1	*
8	Ø	
9	1	*

Fig. B.7 Frequency distribution of ferrous waste (kg/hh/wk)
EACH * REPRESENTS 15 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø.Ø	38Ø	**************************
Ø.5	543	*************************************
1.Ø	2Ø5	**************
1.5	84	******
2.Ø	43	***
2.5	12	*
3.Ø	2	*
3.5	5	*
4.Ø	Ø	
4.5	Ø	
5.Ø	1	*
5.5	Ø	
6.Ø	Ø	
6.5	2	*

Fig. B.8 Frequency distribution of non-ferrous waste (kg/hh/wk)
EACH * REPRESENTS 20 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.0	986	**
0.2	229	************
0.4	35	**
0.6	11	*
0.8	8	*
1.0	2	*
1.2	1	*
1.4	2	*
1.6	0	
1.8	1	*
2.0	0	
2.2	0	
2.4	2	*

Fig. B.9 Frequency distribution of waste textiles (kg/hh/wk)
EACH * REPRESENTS 25 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	1190	**
2	68	***
4	10	*
6	3	*
8	2	*
10	2	*
12	1	*
14	0	
16	0	
18	0	
20	1	*

Fig. B.10 Frequency distribution of waste glass (kg/hh/wk)
EACH * REPRESENTS 15 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	592	**
1	410	****************************
2	162	***********
3	52	****
4	21	**
5	18	**
6	10	*
7	6	*
8	3	*
9	0	
10	2	*
11	1	*

Fig. B.11 Frequency distribution of plastic film waste (kg/hh/wk)
EACH * REPRESENTS 15 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.0	218	***************
0.2	633	***
0.4	268	******************
0.6	89	******
0.8	43	***
1.0	11	*
1.2	5	*
1.4	5	*
1.6	3	*
1.8	0	
2.0	1	*
2.2	0	
2.4	1	*

Fig. B.12 Frequency distribution of dense plastic waste (kg/hh/wk)

```
EACH * REPRESENTS  2Ø OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
   Ø.Ø       867     ********************************************
   Ø.5       367     *******************
   1.Ø        26     **
   1.5         7     *
   2.Ø         5     *
   2.5         1     *
   3.Ø         2     *
   3.5         Ø
   4.Ø         1     *
   4.5         Ø
   5.Ø         Ø
   5.5         Ø
   6.Ø         Ø
   6.5         Ø
   7.Ø         1     *
```

Fig. B.13 Frequency distribution of miscellaneous combustible waste (kg/hh/wk)

```
EACH * REPRESENTS  2Ø OBSERVATIONS

MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     Ø       971     *************************************************
     1       186     **********
     2        49     ***
     3        26     **
     4        15     *
     5         6     *
     6         4     *
     7         8     *
     8         6     *
     9         2     *
    1Ø         2     *
    11         Ø
    12         2     *
```

Fig. B.14 Frequency distribution of miscellaneous non-combustible waste (kg/hh/wk)

EACH * REPRESENTS 25 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	1127	***
1	1Ø7	*****
2	23	*
3	5	*
4	5	*
5	2	*
6	4	*
7	1	*
8	Ø	
9	Ø	
1Ø	1	*
11	1	*
12	Ø	
13	1	*

Fig. B.15 Frequency distribution of pernicious items (kg/hh/wk)

EACH * REPRESENTS 25 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø.Ø	1187	***
Ø.5	77	****
1.Ø	1Ø	*
1.5	1	*
2.Ø	Ø	
2.5	1	*
3.Ø	Ø	
3.5	Ø	
4.Ø	Ø	
4.5	Ø	
5.Ø	Ø	
5.5	Ø	
6.Ø	Ø	
6.5	Ø	
7.Ø	Ø	
7.5	Ø	
8.Ø	1	*

Fig. B.16 Frequency distribution of fines waste (kg/hh/wk)

```
 EACH * REPRESENTS  2Ø OBSERVATIONS

 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
     Ø.Ø      993    **************************************************
     Ø.1      221    ************
     Ø.2       31    **
     Ø.3        9    *
     Ø.4        9    *
     Ø.5        5    *
     Ø.6        2    *
     Ø.7        2    *
     Ø.8        1    *
     Ø.9        1    *
     1.Ø        1    *
     1.1        Ø
     1.2        Ø
     1.3        Ø
     1.4        Ø
     1.5        1    *
     1.6        Ø
     1.7        1    *
```

Fig. B.17 Frequency distribution of kitchen waste (% weight)

```
EACH * REPRESENTS  10 OBSERVATIONS


MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     0         84     *********
    10        130     *************
    20        236     ************************
    30        279     ****************************
    40        255     **************************
    50        166     *****************
    60         76     ********
    70         30     ***
    80          7     *
    90          3     *
```

Fig. B.18 Frequency distribution of garden waste (% weight)

```
EACH * REPRESENTS  20 OBSERVATIONS


MIDDLE OF    NUMBER OF
INTERVAL     OBSERVATIONS
     0        980     *************************************************
    10        129     *******
    20         55     ***
    30         26     **
    40         24     **
    50         23     **
    60         12     *
    70          8     *
    80          3     *
    90          1     *
   100          5     *
```

Fig. B.19 Frequency distribution of scrap paper waste (% weight)

```
EACH * REPRESENTS  15 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      0     161     ***********
      5     636     *******************************************
     10     290     ********************
     15     109     ********
     20      39     ***
     25      21     **
     30       4     *
     35       1     *
     40       3     *
     45       1     *
     50       0
     55       1     *
```

Fig. B.20 Frequency distribution of waste newsprint (% weight)

```
EACH * REPRESENTS  10 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      0     242     *************************
      5     269     ***************************
     10     256     **************************
     15     152     ****************
     20     129     *************
     25      78     ********
     30      45     *****
     35      34     ****
     40      13     **
     45      12     **
     50      15     **
     55       7     *
     60       6     *
     65       5     *
     70       0
     75       3     *
```

Fig. B.21 Frequency distribution of waste cardboard (% weight)
EACH * REPRESENTS 15 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	270	******************
5	708	**
10	215	***************
15	46	****
20	14	*
25	3	*
30	6	*
35	3	*
40	0	
45	0	
50	1	*

Fig. B.22 Frequency distribution of ferrous waste (% weight)
EACH * REPRESENTS 15 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	283	*******************
5	591	**
10	250	*****************
15	86	******
20	27	**
25	12	*
30	6	*
35	8	*
40	1	*
45	1	*
50	0	
55	0	
60	1	*

Fig. B.23 Frequency distribution of non-ferrous waste (% weight)
EACH * REPRESENTS 2Ø OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	985	***
2	212	***********
4	47	***
6	8	*
8	5	*
1Ø	2	*
12	Ø	
14	1	*
16	1	*
18	1	*
2Ø	1	*
22	2	*
24	Ø	
26	1	*

Fig. B.24 Frequency distribution of waste textiles (% weight)
EACH * REPRESENTS 2Ø OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø	959	***
5	199	**********
1Ø	51	***
15	21	**
2Ø	9	*
25	7	*
3Ø	5	*
35	3	*
4Ø	4	*
45	4	*
5Ø	2	*
55	1	*
6Ø	Ø	
65	Ø	
7Ø	Ø	
75	1	*

Fig. B.25 Frequency distribution of waste glass (% weight)
EACH * REPRESENTS 10 OBSERVATIONS

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
    0       366   *************************************
    5       329   *********************************
   10       221   ***********************
   15       132   **************
   20        80   ********
   25        53   ******
   30        38   ****
   35        14   **
   40        12   **
   45         8   *
   50         5   *
   55         2   *
   60         2   *
   65         2   *
   70         0
   75         1   *
   80         1   *
```

Fig. B.26 Frequency distribution of plastic film waste (% weight)
EACH * REPRESENTS 25 OBSERVATIONS

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
    0      1115   *********************************************
   10       143   ******
   20         4   *
   30         2   *
   40         0
   50         0
   60         0
   70         0
   80         0
   90         0
  100         2   *
```

Fig. B.27 Frequency distribution of dense plastic waste (% weight)

EACH * REPRESENTS 15 OBSERVATIONS

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      0     692     ***********************************************
      4     503     **********************************
      8      49     ****
     12      14     *
     16       4     *
     20       1     *
     24       1     *
     28       1     *
     32       0
     36       0
     40       0
     44       1     *
```

Fig. B.28 Frequency distribution of miscellaneous combustible waste (% weight)

EACH * REPRESENTS 20 OBSERVATIONS

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      0     967     *************************************************
     10     190     **********
     20      54     ***
     30      29     **
     40      12     *
     50       4     *
     60       4     *
     70       4     *
     80       1     *
     90       0
    100       1     *
```

Fig. B.29 Frequency distribution of miscellaneous non-combustible waste (% weight)

```
 EACH * REPRESENTS  25 OBSERVATIONS


MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      Ø     1Ø28    ******************************************
      5     151     *******
     1Ø      39     **
     15      19     *
     2Ø      11     *
     25       5     *
     3Ø       2     *
     35       1     *
     4Ø       3     *
     45       3     *
     5Ø       Ø
     55       1     *
     6Ø       1     *
     65       Ø
     7Ø       1     *
     75       1     *
```

Fig. B.3Ø Frequency distribution of pernicious items (% weight)

```
 EACH * REPRESENTS  25 OBSERVATIONS


MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
      Ø.    1133    **********************************************
      4     118     *****
      8       9     *
     12       3     *
     16       1     *
     2Ø       Ø
     24       Ø
     28       1     *
     32       Ø
     36       1     *
```

Fig. B.31 Frequency distribution of fines waste (% weight)

```
 EACH * REPRESENTS  15 OBSERVATIONS


 MIDDLE OF    NUMBER OF
 INTERVAL     OBSERVATIONS
       Ø      631     *******************************************
       5      498     **********************************
      1Ø       74     *****
      15       16     **
      2Ø       13     *
      25       13     *
      3Ø        4     *
      35        3     *
      4Ø        7     *
      45        1     *
      5Ø        3     *
      55        1     *
      6Ø        Ø
      65        2     *
```

Fig. B.32 Distribution of the average between-week difference in total waste arisings (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	18	******************
2	29	*****************************
4	16	****************
6	5	*****
8	4	****
10	0	
12	0	
14	0	
16	1	*

Fig. B.33 Distribution of the average between-week difference in kitchen waste (kg/hh/wk)

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
    Ø        17   *****************
    1        31   *******************************
    2        13   *************
    3         7   *******
    4         1   *
    5         1   *
    6         1   *
    7         2   **
```

Fig. B.34 Distribution of the average between-week difference in garden waste (kg/hh/wk)

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
    Ø        48   ************************************************
    1        14   **************
    2         6   ******
    3         3   ***
    4         Ø
    5         1   *
    6         Ø
    7         Ø
    8         1   *
```

Fig. B.35 Distribution of the average between-week difference in scrap paper waste (kg/hh/wk)

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   Ø.Ø        4   ****
   Ø.2       32   ********************************
   Ø.4       22   **********************
   Ø.6        5   *****
   Ø.8        5   *****
   1.Ø        2   **
   1.2        1   *
   1.4        1   *
   1.6        1   *
```

Fig. B.36 Distribution of the average between-week difference in waste newsprint (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø.Ø	16	****************
Ø.5	28	****************************
1.Ø	12	************
1.5	9	*********
2.Ø	4	****
2.5	2	**
3.Ø	Ø	
3.5	1	*
4.Ø	Ø	
4.5	1	*

Fig. B.37 Distribution of the average between-week difference in waste cardboard (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø.Ø	7	*******
Ø.2	32	********************************
Ø.4	15	***************
Ø.6	9	*********
Ø.8	7	*******
1.Ø	1	*
1.2	Ø	
1.4	1	*
1.6	Ø	
1.8	Ø	
2.Ø	Ø	
2.2	1	*

Fig. B.38 Distribution of the average between-week difference in ferrous waste (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
Ø.Ø	4	****
Ø.1	2Ø	********************
Ø.2	1Ø	**********
Ø.3	1Ø	**********
Ø.4	6	******
Ø.5	4	****
Ø.6	7	*******
Ø.7	3	***
Ø.8	3	***
Ø.9	3	***
1.Ø	1	*
1.1	Ø	

Fig. B.39 Distribution of the average between-week difference in non-ferrous waste (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	22	**********************
0.05	28	****************************
0.10	14	**************
0.15	3	***
0.20	2	**
0.25	1	*
0.30	0	
0.35	0	
0.40	0	
0.45	2	**
0.50	0	
0.55	1	*

Fig. B.40 Distribution of the average between-week difference in waste textiles (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.0	41	***
0.5	20	********************
1.0	6	******
1.5	5	*****
2.0	0	
2.5	0	
3.0	0	
3.5	1	*

Fig. B.41 Distribution of the average between-week difference in waste glass (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.0	14	**************
0.4	26	**************************
0.8	18	******************
1.2	3	***
1.6	5	*****
2.0	3	***
2.4	3	***
2.8	0	
3.2	1	*

Fig. B.42 Distribution of the average between-week difference in plastic film waste (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.0	9	*********
0.1	42	**
0.2	13	*************
0.3	5	*****
0.4	0	
0.5	0	
0.6	1	*
0.7	2	**
0.8	1	*

Fig. B.43 Distribution of the average between-week difference in dense plastic waste (kg/hh/wk)

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0.00	6	******
0.05	20	********************
0.10	19	*******************
0.15	10	**********
0.20	9	*********
0.25	2	**
0.30	1	*
0.35	2	**
0.40	1	*
0.45	1	*
0.50	0	
0.55	1	*
0.60	1	*

Fig. B.44 Distribution of the average between-week difference in miscellaneous combustible waste (kg/hh/wk)

EACH * REPRESENTS 2 OBSERVATIONS

MIDDLE OF INTERVAL	NUMBER OF OBSERVATIONS	
0	60	******************************
1	6	***
2	3	**
3	2	*
4	1	*
5	0	
6	0	
7	0	
8	1	*

Fig. B.45 Distribution of the average between-week difference in miscellaneous non-combustible waste (kg/hh/wk)

```
EACH * REPRESENTS   2 OBSERVATIONS

MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   Ø.Ø       51    **************************
   Ø.5       13    *******
   1.Ø        6    ***
   1.5        Ø
   2.Ø        2    *
   2.5        Ø
   3.Ø        Ø
   3.5        Ø
   4.Ø        1    *
```

Fig. B.46 Distribution of the average between-week difference in pernicious items (kg/hh/wk)

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   Ø.ØØ      32    ********************************
   Ø.Ø5      15    ***************
   Ø.1Ø       8    ********
   Ø.15       6    ******
   Ø.2Ø       4    ****
   Ø.25       3    ***
   Ø.3Ø       1    *
   Ø.35       2    **
   Ø.4Ø       1    *
   Ø.45       1    *
```

Fig. B.47 Distribution of the average between-week difference in fines waste (kg/hh/wk)

```
MIDDLE OF   NUMBER OF
INTERVAL    OBSERVATIONS
   Ø.Ø       44    ********************************************
   Ø.4       18    ******************
   Ø.8        5    *****
   1.2        5    *****
   1.6        Ø
   2.Ø        Ø
   2.4        Ø
   2.8        Ø
   3.2        1    *
```

APPENDIX C

WASTE CHARACTERISITICS OF SELECTED TYPES OF URBAN NEIGHBOURHOOD IN BIRMINGHAM

C.1 Introduction

This Appendix presents a series of illustrated descriptions of residential areas in Birmingham and their waste characteristics. The descriptions have been constructed on the basis of the method of area-estimation of waste arisings described in Chapter 7. For each area the composition of household waste arisings together with the distribution of household types (classified according to household size, tenure and economic activity) are given (Figures C.1 to C.8). The descriptions are illustrated by photographs showing the typical residential characteristics of each area (Plates C.1 to C.8). The purpose of the descriptions is to demonstrate in clear, practical terms the way in which households tend to group together into discrete urban neighbourhoods, and to demonstrate how the area-based waste arisings model is able to differentiate the waste characteristics of the neighbourhood types.

Altogether, eight types of area are described. These do not represent a comprehensive catalogue of all types of urban area; rather they are intended to reflect a cross-section of residential areas in Birmingham, as an illustration of the principle and technique of area waste estimation.

C.2 Urban Neighbourhood Type 1: Post War Municipal Estates

General Description

Purpose-built municipal estates of post-war construction with shops, public houses, churches etc. located within the boundaries of the estate. A large proportion of the residents are housed in low-rise or high-rise blocks. Public open spaces are provided but few private gardens. The socio-economic status of the residents is usually low with a higher than average numbers of incidence of economic inactivity.

Typical Household Waste Characteristics

Total waste arisings per household are below average for Birmingham. The proportion of organic kitchen waste is relatively high with smaller proportional quantities of packaging materials particularly paper and glass.

C.3 Urban Neighbourhood Type 2: Older Inner City Residential Areas

General Description

Areas of pre-1914 terraced housing typical of Victorian urban industrial structure, with worker's homes built close to factories (the photograph shows housing built to serve the nearby Dunlop works). Houses are of the two-up, two-down type, fronting directly onto pavements and devoid of front gardens. Solid fuel is often burned on open grates. These areas frequently house an elderly population.

Typical Household Waste Characteristics

Total waste arisings per household are more than 1 kg/week below the Birmingham average, but proportions of ferrous metal and fines are above average.

C.4 Urban Neighbourhood Type 3: Family Housing on Modern Estates

General Description

Modern, medium-sized housing which is part of either a large, private scheme or a newly-built local authority development. Houses are generally of the semi-detatched or linked residence type, but individually centally heated and with private garden plots. Residents are typically young families of medium socio-economic status.

Typical Household Waste Characteristics

Mean total waste arisings exceed the Birmingham average with large quantities of waste derived directly or indirectly from food consumption (e.g. kitchen waste, paper packaging, plastic film). The proportion of fines and the proportion of 'miscellaneous' wastes are below average.

C.5 Urban Neighbourhood Type 4: Private Rented Multiple Occupancy Flats

General Description

Areas of large, three-storey Victorian housing converted into rented flats and frequently occupied by students or young couples without children (hence the term 'bedsitter land' used to describe these areas). Although the houses generally have gardens these are frequently turned into forecourts or are else untended.

Typical Household Waste Characteristics

Total waste arisings per household are average for Birmingham, but levels of paper and glass waste are above average in both absolute and percentage terms.

C.6 Urban Neighbourhood Type 5: Inter-War Local Authority Housing

General Description

Local authority housing schemes built between 1919 and 1939. Houses are generally of the semi-detatched or block terraced type with small gardens and sometimes space allocated on private allotments. Residents are typically large families with school-age children.

Typical Household Waste Characteristics

The proportions of individual waste components are broadly representative of the Birmingham average but total waste arisings are above average.

C.7 Urban Neighbourhood Type 6: Inter-War Speculative Suburban Dwellings

General Description

Areas of owner occupied suburban dwellings built between the wars. The properties are generally of a 'tooth and gap' style, semi-detatched or individual bungalows frequently occupied by middle aged or retired couples with no children living with them. The greater amount of leisure time available to these households often means that more time is spent gardening and in the preparation of meals.

Typical Household Waste Characteristics

Total waste arisings per household are below average for Birmingham but the proportion of vegetable and putrescible material derived from both kitchen and garden origins is above average.

C.8 Urban Neighbourhood Type 7: Modern, High Quality Housing

General Description

Areas of newly built owner occupied 'excutive' or 'superior' homes located on small private estates often on the urban fringe. Dwellings are generally detatched or spacious semi-detatched and equipped with oil or gas central heating. Residents are typically young or middle-aged families with the head of household in managerial type employment.

Typical Household Waste Characteristics

Total waste arisings per household are above the Birmingham average with notably elevated levels of packaging materials, particularly glass and dense plastic.

C.9 Urban Neighbourhood Type 8: Traditional High Status Suburbia

General Description

Areas of large, detatched owner occupied houses, sometimes built in mock Tudor or Georgian style. Properties are frequently located in suburbs where smoke restrictions do not apply. Large, well tended gardens are also a feature of this type of area. The socio-economic status of the residents is predominantly high.

Typical Household Waste Characteristics

Total waste per household are 2 kg/week above the average Birmingham average with higher absolute quantities of all types of waste. Garden waste and glass are above average in percentage terms, with slightly below average proportions of kitchen waste.

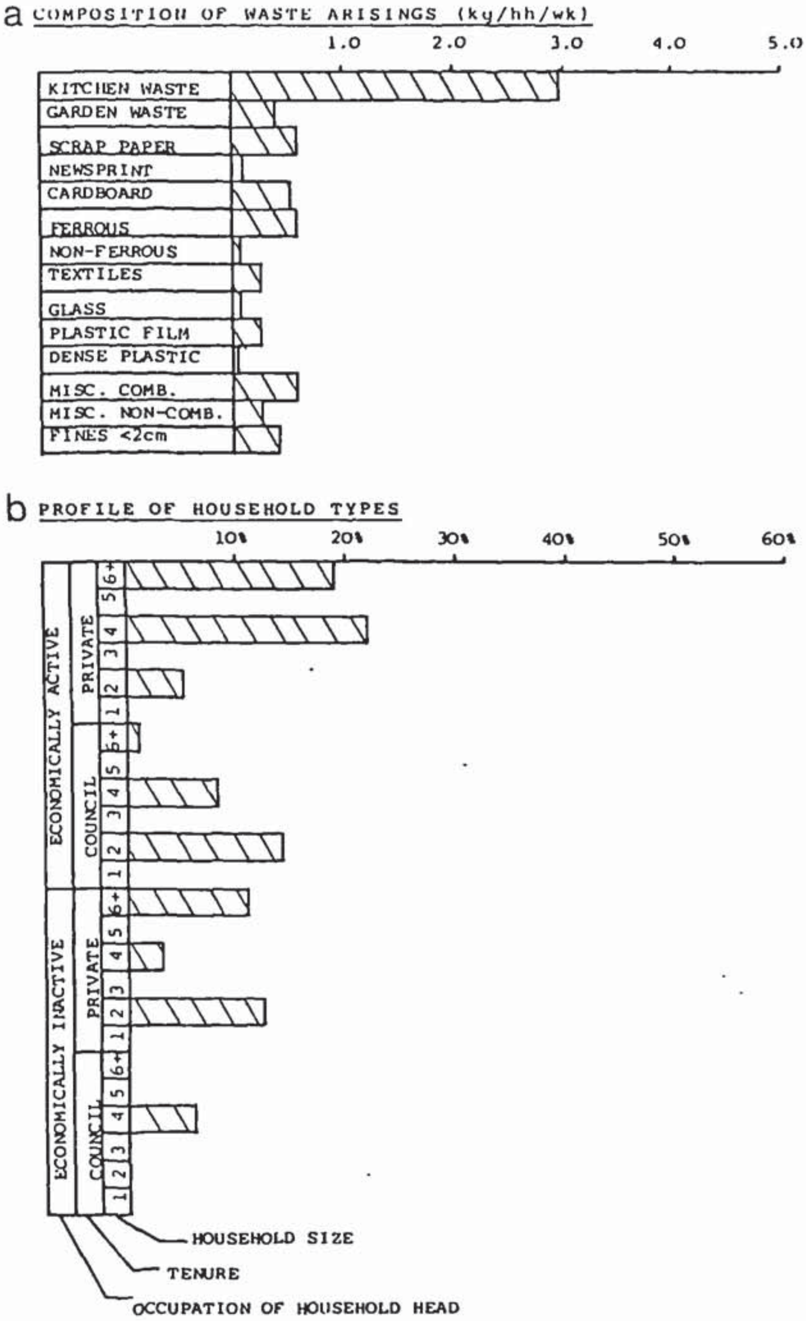

Fig. C.1 Profiles of (a)waste composition and (b)household types for a post-war municipal estate (E.D.: CNBF52)

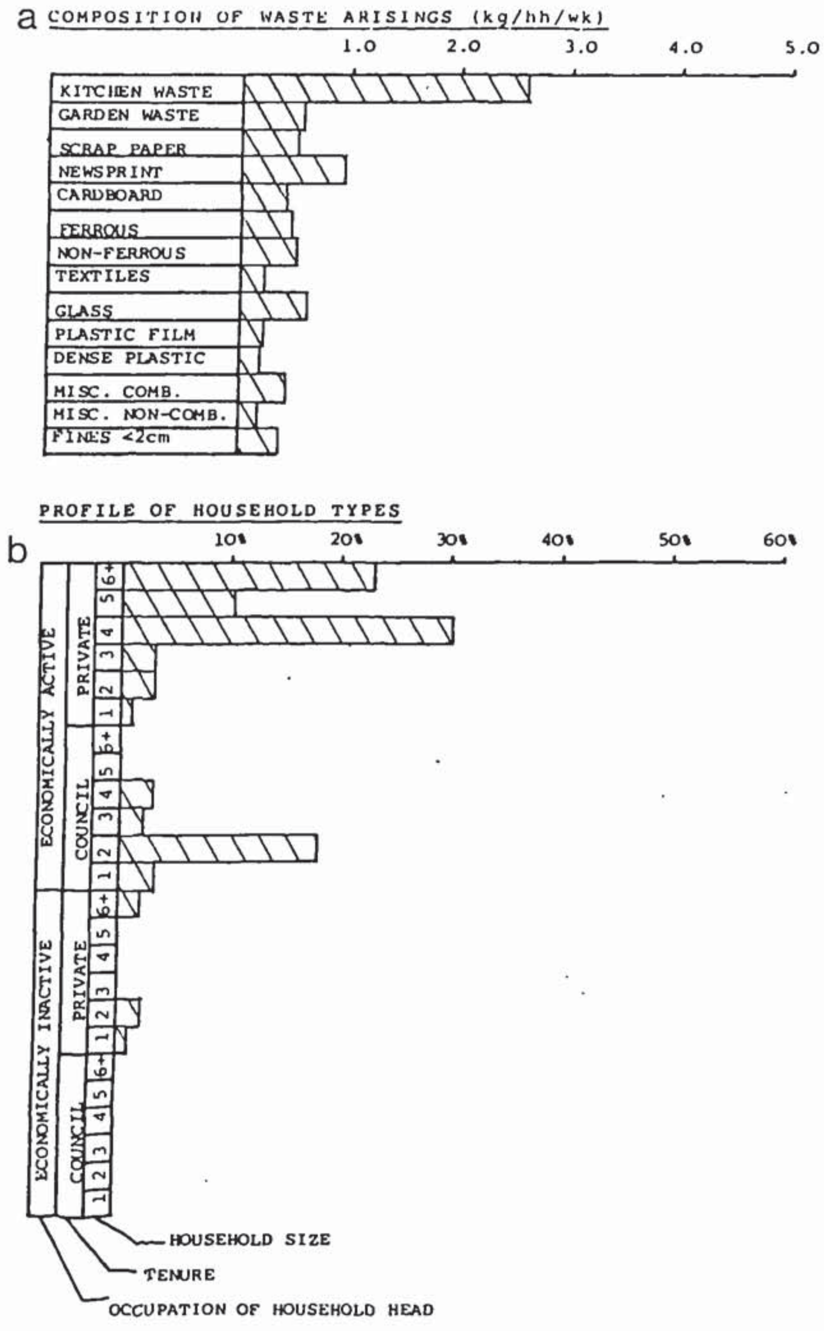

Fig. C.2 Profiles of (a) waste composition and (b) household types for an older inner city residential area (E.D.: CNAJ42)

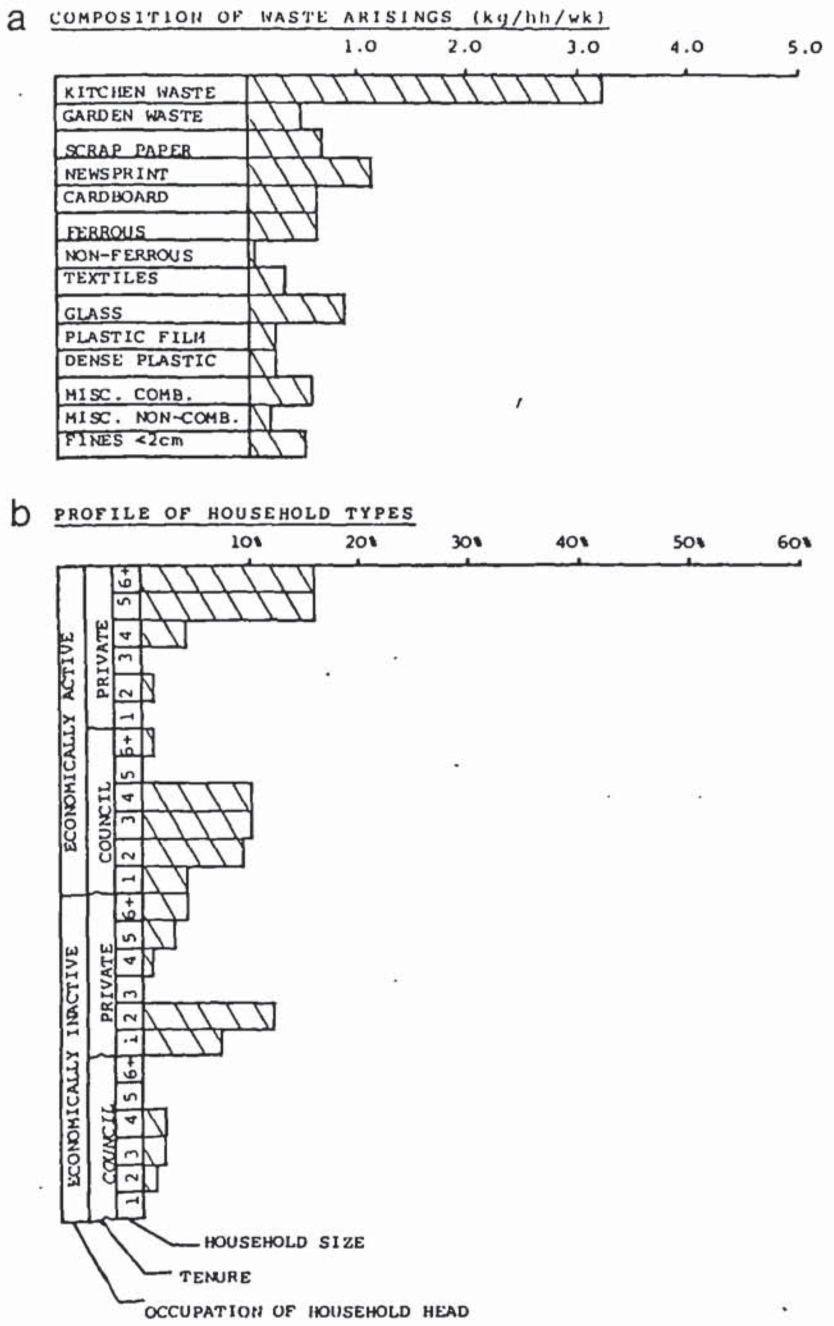

Fig. C.3 Profiles of (a)waste composition and (b)household types for family housing on a modern estate (E.D.: CNAJ65)

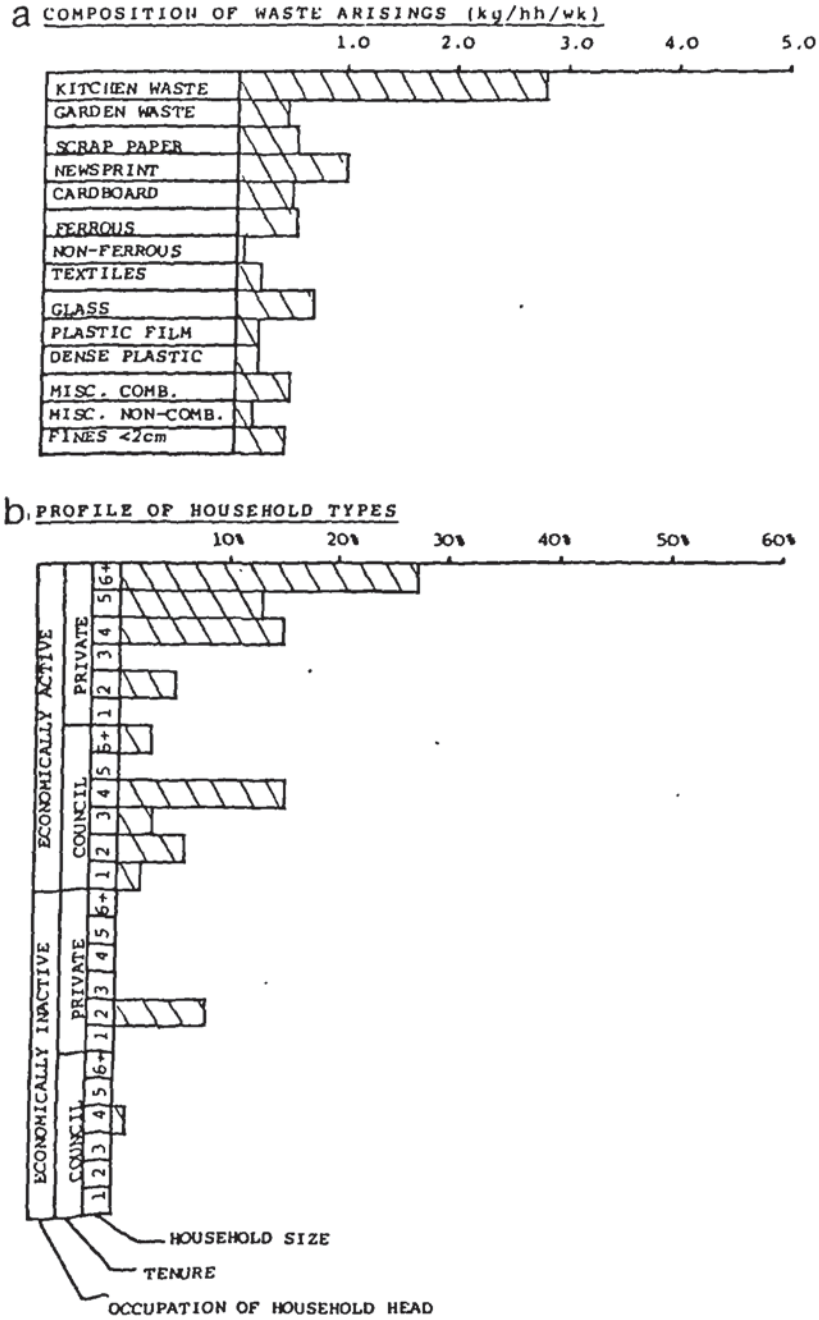

Fig. C.4 Profiles of (a)waste composition and (b)household types for private-rented multioccupancy flats (E.D.: CNAJO3)

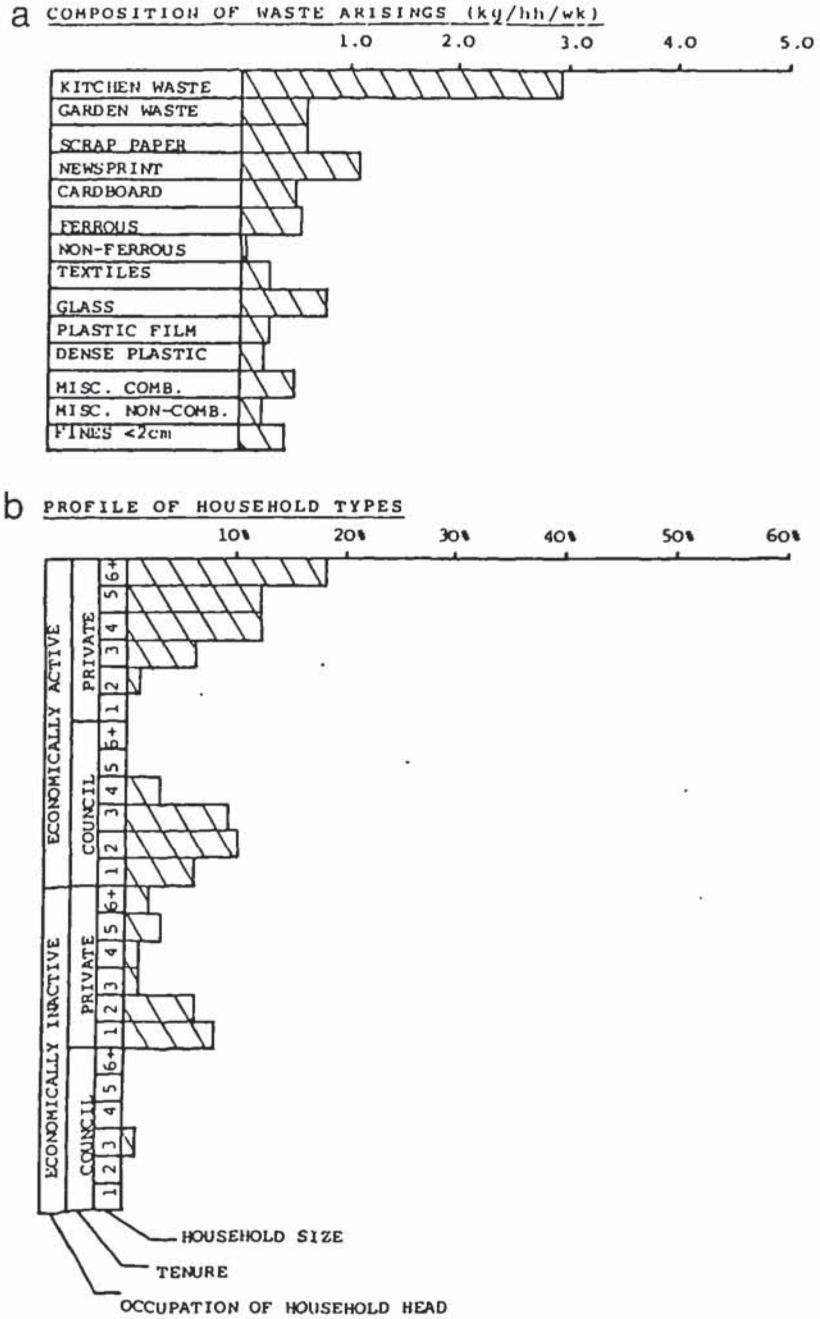

Fig. C.5 Profiles of (a)waste composition and (b)household types for inter-war local authority housing (E.D.: CNBM15)

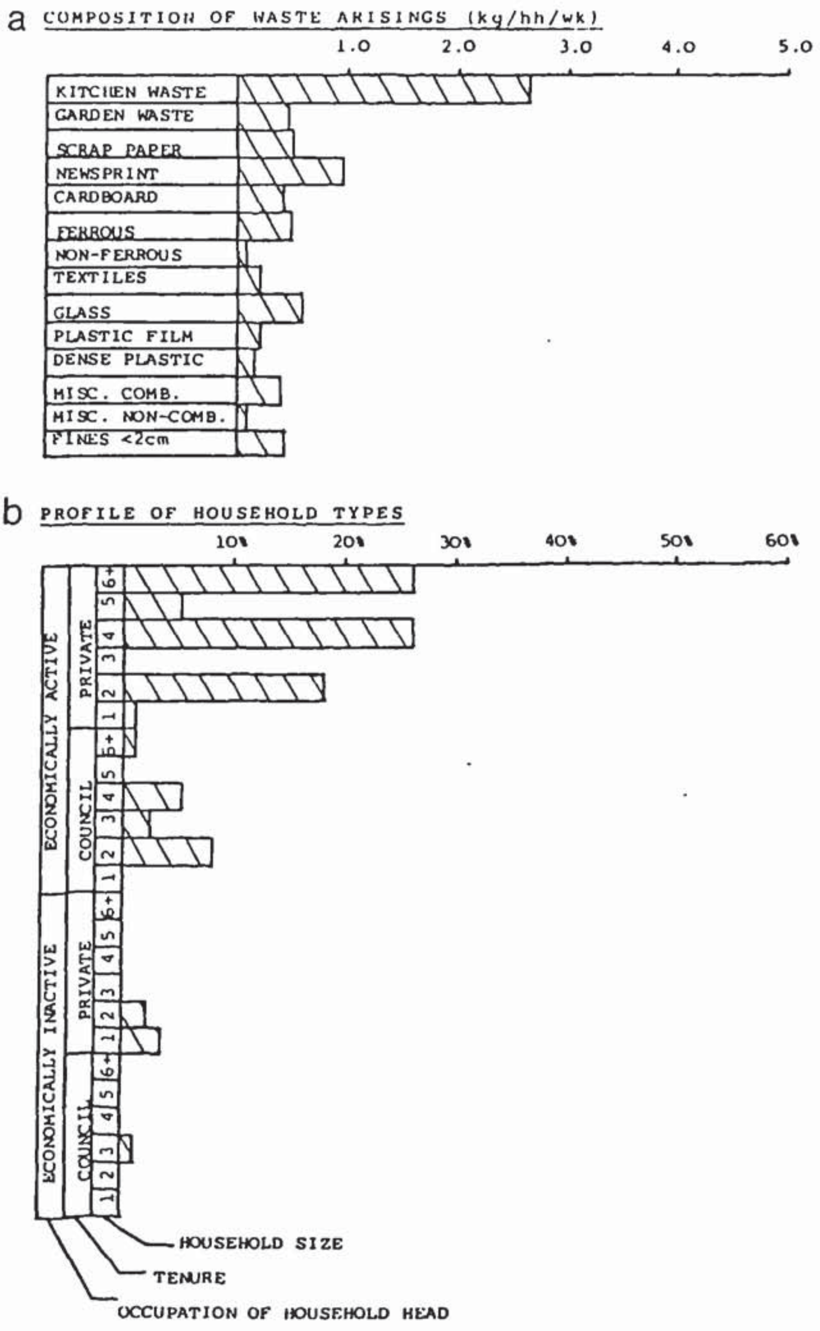

Fig C.6 Profiles of (a)waste composition and (b)household types for inter-war speculative suburban dwellings (E.D.: CNAJ48)

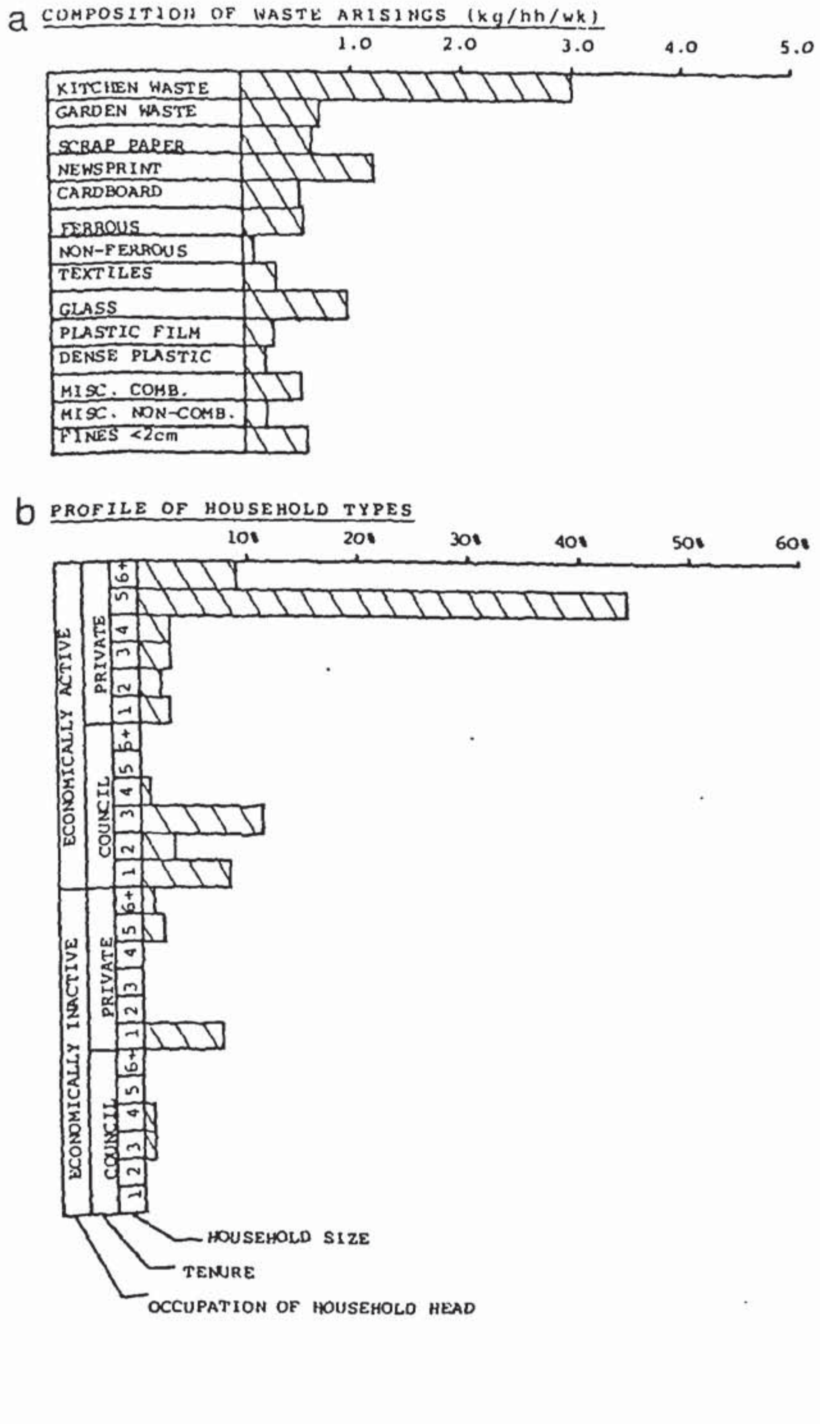

Fig. C.7 Profiles of (a)waste composition and (b)household types for modern high quality housing (E.D.: CNBU44)

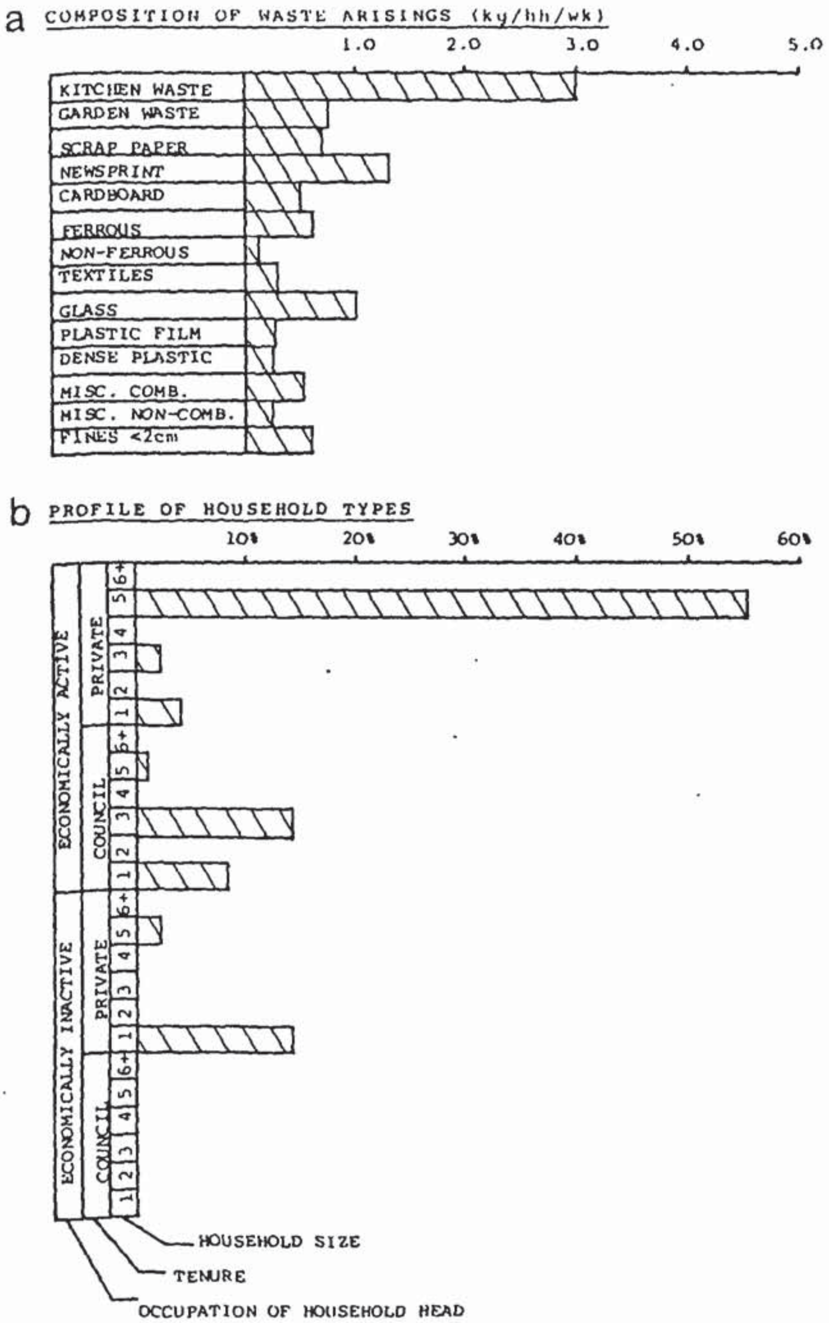

Fig. C.8 Profiles of (a) waste composition and (b) household types for traditional high status suburbia (E.D.: CNBU45)

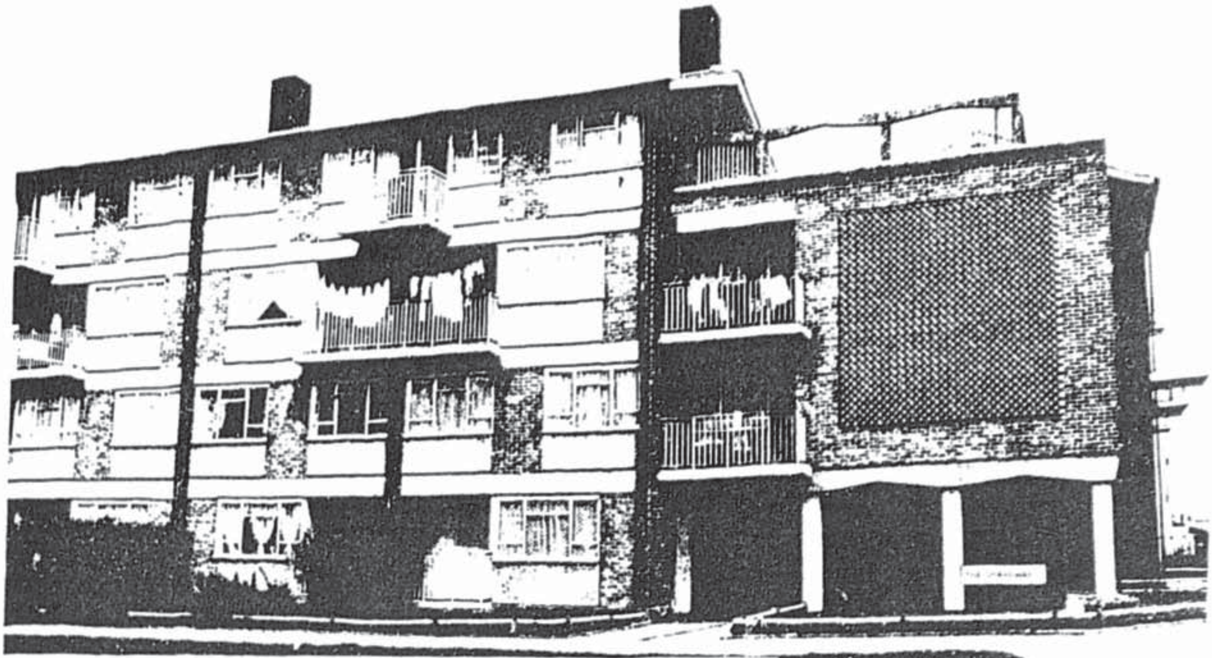

Plate C.1 Housing on Post-War Municipal Estate

Plate C.2 Housing in Older Inner-City Residential Area

Plate C.4 Private Rented Multiple Occupancy Flats

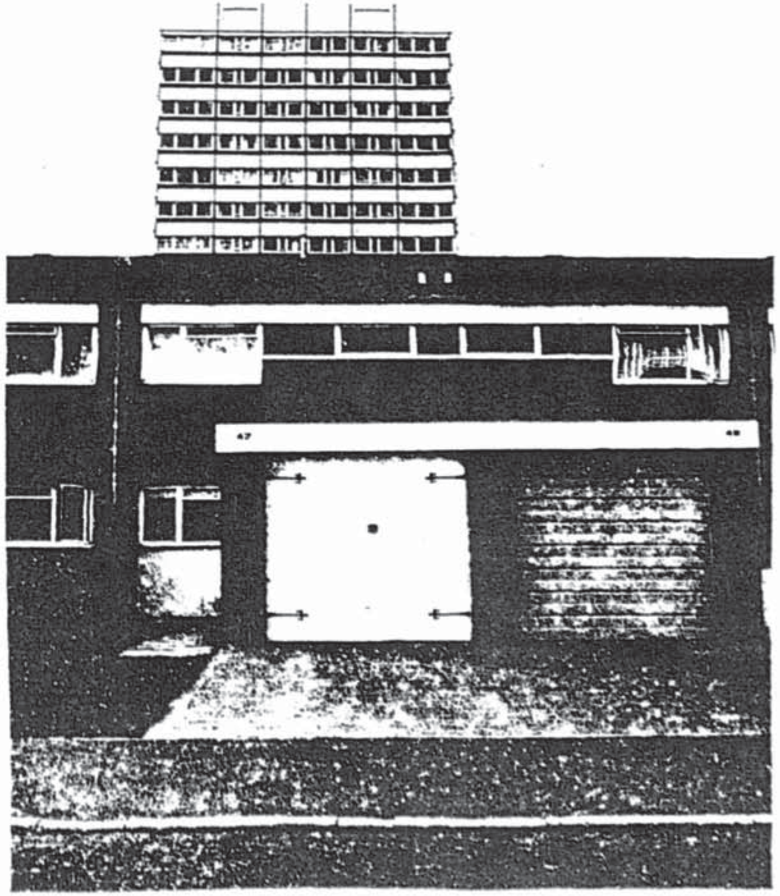

Plate C.3 Family Housing on Modern Estate

Plate C.5   Inter-War Local Authority Housing

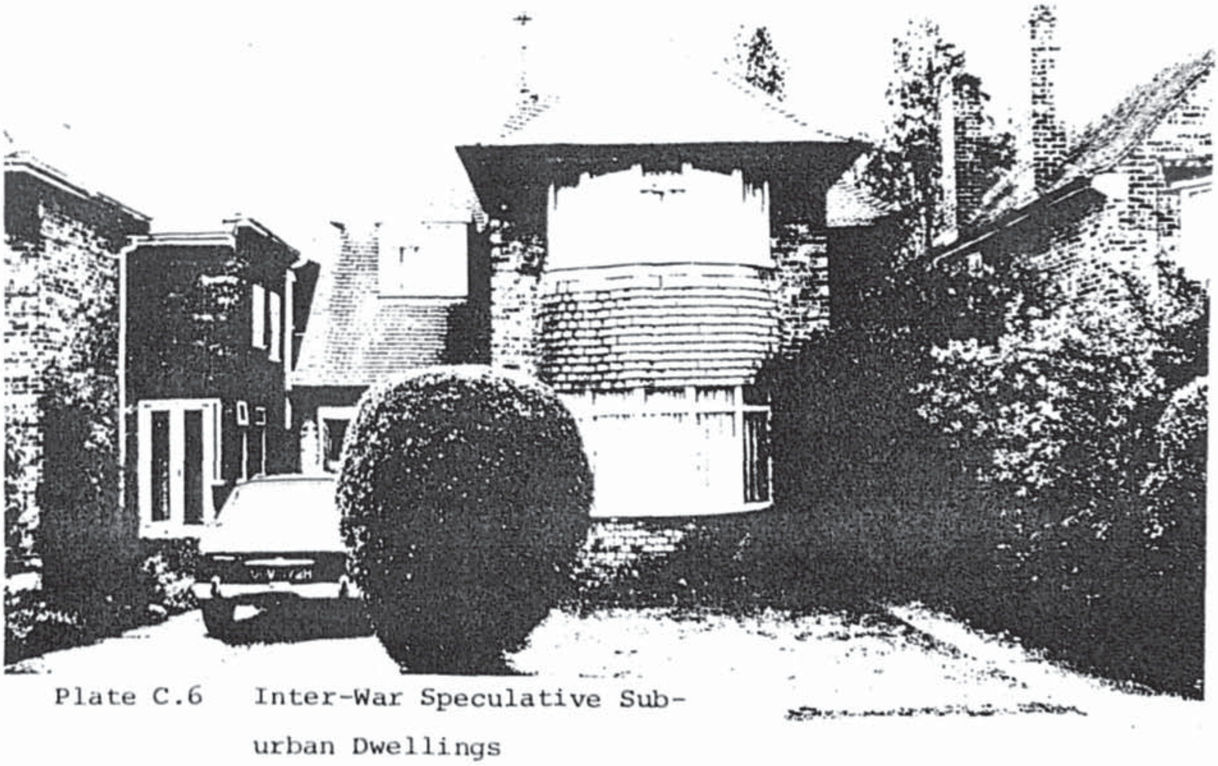

Plate C.6   Inter-War Speculative Sub-urban Dwellings

Plate C.7 Modern High Quality Housing

Plate C.8 Traditional High Status Suburbia

APPENDIX D

PUBLISHED WORK

1. MUNICIPAL ENGINEERING 1 December 1981

Exactly What Do Your Dustbins Contain?

2. SURVEYOR 27 May 1982

Dustbin Study Sets Forecast Factors.

3. WASTES MANAGEMENT October 1982

Improving the Methods of Estimating and Forecasting Domestic Refuse.

4. WASTES MANAGEMENT April 1984

A New Approach to Household Waste Analysis and Forecasting.

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