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THE DEVELOPMENT OF A SOLID WASTE

MANAGEMENT STRATEGY

A thesis of this kind could have been impossible without the assistance of a large number of people. I am indebted to the staff of the Waste Disposal Authority, especially the Council, for their help and advice throughout the work, and their provision of the basic data for this work. I also wish to thank the various questions which gave me the opportunity to study the subject. Particular thanks are due to the District supervisors of this project, Mr. J. W. [unclear] and Mr. R. T. [unclear], to Mr. L. A. Denny and Mr. W. L. Price. The facilities of the University of Aston were available, and I would like to thank the various supervisors of the project, Dr. F. R. Chidley, Mr. J. G. [unclear] and Mr. M. K. Hussey for their help and advice. I also thank Mr. D. C. Walker, of the University and the Harwell Laboratory, for some valuable information. Financial support was provided by the West Midlands County Council, and by the Science Research Council (Industrial Studentship). Finally, I would like to thank Mrs. S. Pickering for her most

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The opinions expressed are entirely my own and do not necessarily represent the views or policies of any of the individuals or bodies above.

THE DEVELOPMENT OF A SOLID WASTE MANAGEMENT STRATEGY

Peter Charles Thomson

PhD

1978

SUMMARY

This research is concerned with the application of operational research techniques in the development of a long-term waste management policy by an English waste disposal authority. The main aspects which have been considered are the estimation of future waste production and the assessment of the effects of proposed systems. Only household and commercial wastes have been dealt with in detail, though suggestions are made for the extension of the effect assessment to cover industrial and other wastes. Similarly, the only effects considered in detail have been costs, but possible extensions are discussed. An important feature of the study is that it was conducted in close collaboration with a waste disposal authority, and so pays more attention to the actual needs of the authority than is usual in such research.

A critical examination of previous waste forecasting work leads to the use of simple trend extrapolation methods, with some consideration of seasonal effects. The possibility of relating waste production to other social and economic indicators is discussed. It is concluded that, at present, large uncertainties in predictions are inevitable; waste management systems must therefore be designed to cope with this uncertainty.

Linear programming is used to assess the overall costs of proposals. Two alternative linear programming formulations of this problem are used and discussed. The first is a straightforward approach, which has been implemented as an interactive computer program. The second is more sophisticated and represents the behaviour of incineration plants more realistically. Careful attention is paid to the choice of appropriate data and the interpretation of the results. Recommendations are made on methods for immediate use, on the choice of data to be collected for future plans, and on the most useful lines for further research and development.

Key words and phrases: solid waste, strategic planning, local government, operational research, linear programming.

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REFERENCES

O. GENERAL INTRODUCTION

The Control of Pollution Act 1974 creates new Waste Disposal Authorities (WDAs), which are to be responsible for the management of most forms of waste in their areas. In England, these authorities are the County Councils. The research described in this thesis was carried out in one such authority, the West Midlands Metropolitan County Council. The Act is being implemented in stages, and some of its major provisions are not in force at the time of writing; but when fully implemented, it will pose many new problems for the WDAs.

One of the requirements of the Act, not yet in force, is that each WDA must produce a Waste Disposal Plan for its area. The Plan should state what wastes are expected to arise, and how they will be dealt with, in the future; official guidelines suggest that it should look about ten years ahead (Department of the Environment, 1977). Such planning has never been required before, so there is no experience to guide those responsible for preparing these plans.

Long-term, county-wide planning of waste management might result in a reduction of the risks to public health and amenities, and the expense to ratepayers and industry, caused by the previous rather haphazard approach. However, the waste management system of a county is so complex that it is difficult to see what effects will follow from any given decision, so the improvements are difficult to achieve. This is especially so in an industrial conurbation like the West Midlands. One way to tackle this complexity, the way adopted in this research, is to use mathematical models of

the situation.

There has been a good deal of work reported in the literature on the use of mathematical models in waste management planning. Most of this work, however, was conducted by modellers largely out of contact with those responsible for day-to-day waste management; studies have been carried out either in universities, for purely academic purposes, or by consultancies such as the Local Government Operational Research Unit, to fulfil specific contracts. The present research, having a different background, provides a different perspective on the problem, which, it is hoped, will be more relevant to the work of the WDAs.

This study was carried out in the Interdisciplinary Higher Degrees Scheme, which brings the research resources of the university to bear on problems in outside organisations. As already mentioned, the outside body in this case was the Waste Disposal Department of the West Midlands County Council, which employed me for the duration of the project. This arrangement not only provided day-to-day contact with the staff of the Department, and free access to its records, but involved the research with the actual formulation of strategy in the Department, thus providing immediate criticism of the initial ideas. Only one other reference has been found to research in a comparable context - this is the much less extensive work of Shields (1972). It is hoped that, as a result of this arrangement, the study will prove to be more directly useful to Waste Disposal Authorities than has been the case with previous research.

The organisational position of this project has resulted in emphasis on different areas from those dealt with in previous work. The aim was to provide an operable system

for use in the production of a Waste Disposal Plan; consequently the models used have been required to fit into the existing organisational structure, to be comprehensible to those responsible for the planning (or rather, to be presented in a comprehensible way), and to operate with data which are actually available. The implications of these requirements will be discussed in detail later.

It may be useful to contrast this approach with those used in some other recent investigations of solid waste management. There have been a number of large-scale investigations in the USA and Canada, normally carried out by consultants (e.g. US Department of Health, Education and Welfare, 1969). Here the aim has been to produce the plan for future management of solid waste, or at least substantial proposals, by consulting suitable experts; the final product is normally a massive technical report, providing extensive numerical data, but suggesting only a very limited range of alternative strategies. The work of Conn (1973) shows how thoroughly the environmental impacts of waste management activities can be investigated, but the fact that only two case studies are dealt with in detail suggests that such rigour would be impracticable in the production of a county plan, unless huge manpower resources were available. The early studies conducted by the Local Government Operational Research Unit (e.g. Brookes and Green (1968), Cooper and Roberts (1971)) tended to produce a recommendation without any clear signs of how it was derived; more recent work (such as Crosby and Renold (1974)) is better in this respect, but now the results are given with the proviso that they are

preliminary and not intended for direct implementation - thus the trend in the Unit's studies seems to be in the direction of more involvement with the local authority, with intermediate reports leading to reconsideration of the requirements. This is approaching the situation intended for the present study.

The development of waste disposal legislation over the period of this study (October 1974 to September 1977) has affected at least one feature of the work, namely that it concentrates almost entirely on domestic and similar wastes. At the beginning of the study, it was anticipated that the Control of Pollution Act requirement for a survey of industrial and other wastes would soon be implemented, and consideration of these wastes was therefore deferred until the results of the survey were available. In fact, this requirement is still not in force at the time of writing - the Government decided to implement the site licensing provisions of the Act first. Consequently the information available on industrial wastes is still relatively scanty. When the survey is carried out, it should become possible to plan for industrial wastes in much the same way as household waste is dealt with here. Since the scarcity of suitable sites for landfill of wastes means that industrial and domestic wastes are competing for space, it is important that all types of waste should be considered when the Waste Disposal Plan is prepared.

This thesis falls into three main sections. Chapters 1-3 consist of introductory and general material on solid waste management, local government and modelling techniques, respectively. Chapters 4-6 are more detailed discussions of the modelling of waste arisings, individual waste

management activities, and the overall problem of waste management strategy for a county. Chapter 7 reviews the research, draws conclusions and provides suggestions for further investigation.

The research was carried out in a number of stages. The first stage was to identify the problem and to define the scope of the study. This was done by reviewing the literature and by consulting with the relevant authorities. The second stage was to design the research methodology. This involved the selection of the research design, the identification of the variables to be studied, and the development of the data collection instruments. The third stage was to collect the data. This was done by conducting interviews, questionnaires, and observations. The fourth stage was to analyze the data. This was done by using statistical techniques and by interpreting the results in the context of the research objectives. The fifth stage was to draw conclusions and to provide suggestions for further investigation.

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1. SOLID WASTES AND THEIR MANAGEMENT

In this chapter the problem of strategic planning for solid waste management will be outlined. This research has been mainly concerned with the problems facing a waste disposal authority, specifically the West Midlands County Council; but to provide a context for the discussion, this introductory material will not be confined to the area of responsibility of these authorities.

Although planning, especially when using the sort of approach adopted in this study, is an abstract, desk-based job, it is essential to have a clear picture of the physical processes involved. A brief description will therefore be given of the processes involved in waste management for an industrial county - both those used at the present and those which must be considered as possibilities for the future. These descriptions will raise those points which will be relevant for the development of long-term plans for waste management; more detailed information on the design and operation of facilities can be found in books such as those by Flintoff and Millard (1969), Skitt (1972) and Hagerty, Pavoni and Heer (1973).

Planning involves a choice between the various possible courses of action, which is made after considering some set of criteria. The criteria to be used in planning solid waste management are not easy to define; and since the waste disposal authorities are part of local government, their criteria should ultimately be determined by public, rather than expert, opinion. The points considered here are the most obvious ones, namely the costs of a decision,

the reliability of the waste disposal system and its environmental effects. The last of these is the most difficult to deal with, since the effects are generally hard to quantify, and their importance (particularly where the effects are localised) is likely to be a matter of political debate. However, these difficulties do not yet seem to be considered in the planning of solid waste management, at least in the U.K. (see Dept. of the Environment, 1976a).

Before considering the methods of waste management, the nature of the wastes under discussion, and the organisation of solid waste management in England, will be briefly outlined. These topics will be considered in more detail later.

1.1 Wastes and their Disposal

Almost all human activities involve the use of some material things as "inputs", either as raw material for processing or as tools. In time, the raw materials will be used up and the tools will be worn out; and the activity will produce "outputs". Some of these will be the desired products, if the activity is one which is intended to give material benefits; in practice, there are also undesired, and perhaps undesirable, outputs. Some of the outputs, including (presumably) all the desired ones, will form inputs to other activities, and the remainder will be discarded as "wastes". Most inputs will be derived from the outputs of other activities, but some will be obtained from the environment as "primary resources", for instance in mineral extraction or the use of air for burning fuel.

The system of exchanging commodities, so that outputs from one activity can form inputs to others, is the concern of economics. The particular viewpoint from which the whole system can be studied is that of input-output analysis (Leontief, (1951), Yan (1969)). This is mainly concerned with the monetary values of the commodities, however; so wastes, which since they are discarded must have zero value, are hard to take into account. Some workers have added consideration of waste disposal to the standard input-output framework; for a discussion of some of this work, and an example of its application, see Victor (1972).

It will be seen that the input-output approach has activity as its central feature, so that the objective becomes to increase the level of activity, especially in the area (known as "consumption") where the main purpose of the activity is enjoyment. The result of this approach is a tendency to increase consumption, hence the rate of use of primary resources and the rate of production of waste. Boulding (1966) argues that it would be preferable to adopt a "spaceman economy" in which no material leaves or enters the economic system, and the objective is not consumption but conservation of the capital resources available. A step towards this has been taken by Ayres and Kneese, with their "materials balance" concept (Ayres and Kneese, (1969); Kneese, Ayres and d'Arge (1970)).

In practice, the economic concept of a waste as having zero value is not entirely satisfactory. It is sometimes found that a material which has been discarded as waste could have been used as an input by another company - hence

the idea of a "wastes exchange" to co-ordinate such arrangements, which has been quite successful in the West Midlands (Cope (1975); Millbank (1975b)). With domestic waste, the quantities produced by a single household are too small to be re-used industrially, but when collected by a local authority the total domestic waste from an area may well include commercially reclaimable quantities of some materials.

In any case, a material is usually referred to as waste at a point where there are still several activities through which it must pass to reach the final stage of its economic existence. Household waste, for instance, must be collected, possibly treated in some way, and transported to the final disposal site. Some anticipation of the fate of the material is therefore involved in referring to it as waste, and this may turn out to be unjustified if recycling is used. This is the reason for using the term "waste management" in preference to "waste disposal". The point is effectively recognised by the Control of Pollution Act 1974, in which a lengthy definition of "waste" (section 30(1)) concludes that "any thing which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the contrary is proved". The "waste disposal authorities" set up by the Act are thus in fact responsible for waste management, including treatment, reclamation and final disposal on land, in their areas. They are not responsible for material released to the atmosphere, discharged into sewers or watercourses, or dumped at sea.

When wastes are released into the atmosphere or the sea, it is expected that they will quickly become dispersed and

diluted in the huge volume of harmless material, and thus have no detectable effect. This does not always turn out to be the case (for instance, air pollution is greater in industrial cities than in the country, despite the circulation of the atmosphere), but it is the intention. This approach means that when the total rate of discharge approaches the limit of the environment's ability to deal with the pollutants, the problems caused are widespread rather than confined to the vicinity of the source. This dispersion has caused difficulties in dealing with such pollution from the economic viewpoint, because of the impossibility of assigning property rights, in the usual sense, to the atmosphere or the ocean (Dales (1968)).

Where waste is deposited on land, the position is rather different. The intention may be to concentrate and contain the waste within an area of land, whose property rights can be owned in the usual way. The process cannot be left entirely uncontrolled, however, because it may present hazards or disamenities to those nearby. Also, it is not easy to ensure that a material is in fact securely contained in a landfill site. Soluble substances, whether originally deposited or resulting from the decomposition of the original material, may be leached out by rainwater percolating through the fill, and carried down to the ground water, which will thus become polluted. Dispersion of the pollutant in the ground water will be slow compared with that in the sea, so a local hazard to water supplies may result. Under suitable conditions, on the other hand, the leaching of pollutants from a land deposit of waste can

provide a slower form of "dilute and disperse" disposal. In any case, it is necessary to consider the geology of a potential landfill site, to ensure that it is suitable for the type of waste to be deposited. This point will be discussed in more detail below.

1.2 Classification of Wastes

This study is concerned with the problems facing a waste disposal authority, so types of waste which are not their responsibility will not be considered. This will exclude gaseous wastes discharged to the atmosphere, and liquids discharged to sewers or watercourses. The term "solid waste" is loosely used to describe the sorts of waste which will be dealt with; though this is, strictly speaking, inaccurate (since liquids which are unacceptable for discharge to sewer, and sludges, are to be included), it will be used in this sense.

As noted above, all the material products of human activity ultimately become wastes. The range of objects and materials found in solid waste is thus enormous, and a thorough classification suitable for all possible purposes is not practicable. A number of different forms of classification are used for different purposes, and it may be necessary to devise new systems when a new problem has to be tackled. Existing systems classify wastes by the premises on which they arise, the nature of any hazard they present, their physical form and chemical composition, and the organisation which deals with them.

The Control of Pollution Act 1974 defines the broad categories of "household", "commercial" and "industrial"

wastes, for which the waste disposal authorities have different degrees of responsibility, according to the premises producing the waste. The Act also mentions farm wastes and mine and quarry wastes, which are not included with the other classes as "controlled" wastes. The wastes from these different sources are expected to be different in nature, but there are some anomalies; for instance, many factories incorporate canteens, producing "domestic-type" waste, and offices, producing "commercial-type" waste, all of which would be classified as industrial waste because the factory is a single concern.

A very general classification according to hazard can be made, grouping wastes as "hazardous", "biodegradable" or "inert". (Biodegradable wastes are those which, like household refuse, contain organic materials which will decompose due to bacterial action). This is a classification used mainly for general consideration of suitable landfill sites, since inert wastes should present little risk of water pollution or other serious effects. For hazardous materials, a more detailed classification according to the type of hazard can be made, indicating whether the waste is oily, acid, contains asbestos, etc. Unless a special facility for a single waste is being considered, however, it is important to remember that a mixture of wastes may present a hazard which does not arise when each waste is handled separately; for instance, mixing acid with sulphide waste produces the highly poisonous hydrogen sulphide gas, which recently killed a man on the Pitsea landfill site (Anon. (1975a)).

A simple division according to physical form can be

made, separating solids, liquids and sludges. The dividing lines between these categories will need to be carefully defined if the classification is to be of any use. In some instances, particularly with industrial wastes, it may be important to know the physical form more precisely, for instance to know whether a material is packed in drums or is being shipped in bulk. The chemical composition of hazardous wastes may be important when considering the hazard they present, particularly when combined. The Department of the Environment has proposed a system for coding the chemical composition of these wastes, for use by the waste disposal authorities when surveying the arisings (Department of the Environment (1976b)). This system was used, and apparently found satisfactory, in the survey carried out by Pencol and the Hazardous Wastes Service of A.E.R.E. Harwell for Cheshire County Council (Hazardous Wastes Service, 1975) but some local authority officers feel that it is not realistic to attempt to classify complex wastes according to their chemical composition, which may not be known even to the producer. On the other hand, an even more complex system has been proposed in a report for the U.S. Environment Protection Agency (Berkowitz, March and Horne (1975)).

In their recommendations for conducting waste surveys (DOE 1976b) the Department of the Environment suggest initial classification of wastes into twelve categories, with some of these being further subdivided. This suggested system is a mixture of the above forms of classification. The categories are as follows:

- (a) Household and commercial waste. This includes street sweepings, the material from gully emptiers and waste

from markets (except livestock markets). It may be subdivided into the public and the private sector wastes, and in the public sector at least a further subdivision can be made between those wastes which are collected and those which are delivered to the disposal point. The latter will include some commercial waste, and that delivered by the public under the provisions of the Civic Amenities Act 1967.

- (b) Medical, surgical and veterinary waste. This is regarded as a distinct waste, presumably because of the potential health hazard which it represents.
- (c) Industrial waste. This is usually dealt with by the private sector at present, though there are some cases where industrial wastes are dealt with at local authority disposal points. This category will include a very wide range of wastes, some of which will be hazardous. Subdivisions into solids, liquids and sludges, or into inert, biodegradable and hazardous materials, may be used. The only common feature of all these wastes is that they are produced on industrial premises.
- (d) Mine and quarry waste. Where this category is important it will usually involve very large amounts of material, but this will probably be inert. Although these wastes are not "controlled" under the Control of Pollution Act 1974, the Department recommends that they should be included in the survey, along with the other wastes which are excluded from control, in order to obtain a complete picture.
- (e) Radioactive waste. This obviously presents a special hazard, and is also subject to special control by central

government under the Radioactive Substances Act 1960.

- (f) Farm waste. This includes waste from livestock markets, but excludes wastes returned to the land for agricultural purposes. Again, such waste is not "controlled" but is included for completeness.
- (g) Waste from construction and demolition. These wastes are mostly inert, and rubble, for instance, is often used as cover material at landfill sites.
- (h) Sewage sludge, cesspool and pail closet contents. Sewage sludge is produced by sewage works, and normally disposed of by landfill or incineration. Cesspool and pail closet contents will be collected by waste collection authorities and dealt with by water authorities, under the provisions of the Control of Pollution Act 1974.
- (i) Old cars, vehicles and trailers. These are normally dealt with by private scrap merchants, though local authorities have a duty to remove abandoned vehicles under the Civic Amenities Act 1967.
- (j) Pulverised household and commercial waste.
- (k) Screenings from household and commercial waste.
- (l) Ash from incineration.

For convenience these residues from waste treatment processes are classified as separate items.

It is suggested that hazardous types of waste which according to the classification are not industrial wastes, such as farm pesticides, should be regarded as industrial wastes and classified in the same detailed way as hazardous industrial wastes.

1.3 Collection of Wastes

If waste is to be dealt with at a special site, it must be transported from the place where it arises, and so must first be collected. For wastes which arise in bulk, this is a trivial operation in management if not always in technical terms. Industrial waste liquids and sludges are collected by tanker vehicles, which for hazardous wastes may be very sophisticated designs (Davies and Mackay (1976)). Solid waste is usually carried in skips which are left at the point where the waste arises, and exchanged when necessary for empty ones brought by the special lorry which will remove the full skip to the disposal site. This system is used for any industrial or commercial premises except the smallest, and (with different types of container) for blocks of flats, schools and other sites producing domestic-type waste in large quantities. For waste from ordinary houses and small shops, however, a lorry load is a very large quantity, and a system of collecting the waste from a large number of sites with the same vehicle is needed to make the transport reasonably economical.

Waste collection in the non-trivial sense is almost entirely the task of local authorities. Perhaps partly for this reason, there is a tendency to regard it as a separate function from waste disposal when conducting studies. This has been reinforced, for workers in England, by the division of responsibility for the two jobs under the Control of Pollution Act 1974; this makes district councils responsible for waste collection, and counties for waste disposal (Holt (1974); Hinchcliffe (1974)). However, collection is an

important part of the management of these wastes - probably the most important in financial terms at least. Also, it is not independent of the arrangements made for disposal; the time that the vehicles must spend delivering their loads to the disposal point will obviously affect the collection schedules, and will be determined by the number and location of disposal points. A complete plan for waste management must therefore include some consideration of collection.

The Control of Pollution Act provides that payments towards the cost of transporting the waste to the disposal site must be made by the disposal authority to the collection authority, if the distance involved is "unreasonable". The details of such arrangements are left to be agreed between the authorities concerned. Such agreements have already been arrived at by some authorities, and in other cases, including that of the West Midlands County, discussions are taking place. However, it is important that the disposal authorities do not regard these agreements as representing the true cost of the transport operation. The formula agreed upon is likely to be simplified, for administrative or political convenience, and will only take into account journeys longer than the agreed "reasonable distance". A more realistic cost model is therefore needed when considering alternative disposal sites or the use of transfer stations. It may, of course, be necessary to consider the direct costs to the disposal authority, in order to arrange finance; in this case the agreed formula will also be needed for the long-term planning. The total cost of transport, regardless of who pays for it, should however be the main consideration.

Almost all collection of domestic refuse is now done using special vehicles, which compress the waste as it is fed in, to achieve a larger vehicle payload. The crew consists of a driver and several collectors (from 2 to 5 depending on local conditions), who actually carry the dustbins to the vehicle. When the vehicle is full, the whole crew may ride with it to the disposal point, or the driver may go alone while the collectors prepare the next part of the round by bringing dustbins to the kerb, or some similar task.

Most authorities collect only during the day, at least in residential areas. This is partly because of the noise produced by compaction vehicles, and partly because of the higher cost of labour (though the increased use of the vehicles should provide some saving, this would not at present offset the labour cost). Collection teams usually start work early in the morning, and are allocated an area to clear each day; once this is done they can go home. Usually a team will collect two or three vehicle loads in a day. The time taken depends on the amount to be collected to some extent, and when arisings are light, the job may be done quite early in the afternoon.

The effect of this collection system is that the rate of arrival of refuse at the disposal point varies considerably during the day. Since all the teams take about the same time to fill a vehicle, there are large peaks in the rate in mid-morning and early afternoon, when many rounds are being completed, whereas in the early morning and late afternoon very little refuse is delivered. Also, some excess collection capacity is provided to cope with exceptional times - such as

immediately after a public holiday, when collections have not been carried out for some days. Consequently, there is usually some slack time at the end of a week, with almost no collection on Friday afternoons. These variations must be taken into account when designing the disposal system.

Obviously the organisation of collection rounds is a complex problem in its own right, so a rigorous calculation of the cost of a new disposal arrangement to the collection authority is difficult if not impossible. This problem will be considered in more detail later; however, as a rough guide, the estimated cost of transporting refuse in collection vehicles in the West Midlands County in 1975 ranged from about 3.5 to 5 pence per tonne-minute (p/t-min) for all districts except Birmingham, while for Birmingham it is about 7.5 p/t-min. This difference is due to the fact that in Birmingham, the entire collection crew rides with the vehicle to the disposal site, whereas in the other districts the trip is done by the driver alone. The vehicle speeds are around 15 mi/hr on average, so the corresponding costs per tonne-mile would range from 14 to 20p for the West Midlands except Birmingham and 30p for Birmingham.

1.4 Treatment of Wastes

There are a number of forms of treatment which may be applied to wastes, either to make it possible to reclaim some or all of the components or to make the waste easier to dispose of. This section will discuss some of the methods now in use, or being proposed for adoption in the near future. Rough indications of the cost and other performance features of the various methods will be given, but for those methods

considered in the more detailed planning, a more rigorous examination will be made later. The costs quoted in this section are from West Midlands C.C. reports (1976a, 1976b), unless otherwise indicated.

Most of the methods discussed are intended mainly for use on household and commercial wastes, or others of a similar nature. Industrial wastes (in the true sense, i.e. wastes from the industrial processes themselves) are so diverse in character that it is impossible to give a discussion of all the forms of treatment which are or might be used. Treatments, particularly for chemical wastes, must be devised specially for each particular case. Examples of such special methods will be found in some of the Department of the Environment Waste Management Papers (DoE 1976 d, e, f, g).

The processes described may be combined to some extent in a single plant. Pulverisation, for instance, is often a preliminary to other processes. The description given here treats each process separately as far as possible.

1.4.1 Mechanical Handling of Refuse

Most of the processes to be described are highly mechanised, and in addition to the actual processing, a practical plant using one of these systems involves some arrangements for handling the input, and any outputs. Because of its complex and unpredictable nature, refuse is a particularly awkward material to handle, and the problems this raises are common to all processing plants, though in varying degrees. These problems will therefore be discussed first. Most of the experience on which these comments are

based has been with incineration plants; this is inevitable, since these are the only mechanical plants which have been widely used for some years, but similar problems must be expected at any type of process plant.

On arrival at the plant the refuse is discharged from the vehicle, either into a bunker or onto a hard floor. In the latter case it will be fed into the input hopper of the process plant by a tractor fitted with a front-loading shovel; these are generally quite reliable machines, but the working environment resulting from this sort of handling in an enclosed space is unpleasant, and the enclosure must be effective to prevent nuisance being caused outside the plant. If a bunker is used, as is the case in most modern British incinerator plants, a grab crane is used to transfer the refuse into the plant proper. As well as improving working conditions the use of a bunker and crane provides greater storage for incoming waste, and thus reduces the effect of fluctuations in input on the running of the plant. Where (as in most new incineration plants) it is intended to run the process for 24 hr/day, and perhaps 7 day/week, this provision is obviously needed to fit in with normal collection arrangements. Also, a short plant shutdown due to some minor fault does not entail diversion of the incoming refuse. For these reasons, the bunker and crane method is usually chosen, and a standby crane may be provided in case of failure.

Within the plants, refuse is usually moved by belt conveyor. The main problem experienced with these is blockage, due to the presence of awkward items such as

lengths of wire in the refuse. Such blockages can easily be cleared manually, but this does require that the conveyors be easily accessible and that labour be available to notice and deal with the obstruction.

Pneumatic transport of refuse through pipes has been used experimentally, and there are a few plants where it is in use for transporting pulverised refuse (for which, obviously, much smaller pipes can be used than would be possible with crude refuse). The size of pipe which would be needed to cater for crude refuse suggests that this method would not be useful except perhaps in very large plants. With both crude and pulverised refuse, there may be problems of wear at bends in the pipe, due mainly to abrasion by the metals and glass in the waste.

1.4.2 Transfer Stations

The purpose of a transfer station is simply to transfer waste from one vehicle to another. The point of this is to reduce transport costs; refuse collection vehicles are expensive to run, and their routes cannot be varied at will because of the disruption this would cause to the collection timetable. The greater flexibility provided by a transfer arrangement may be seen as an advantage in itself, although in principle the same results could be achieved without transfer at greater cost.

Usually the waste is transferred into large lorries, having a payload of the order of 10 tonnes. The cost of transport in these vehicles is estimated at about 1.3 p/t-min, or 4p/t-mile - much less than the cost with collection vehicles,

though this is partly due to the fact that these vehicles are used over longer distances and achieve higher average speeds. The cost of the transfer operation itself must, of course, also be taken into account. This depends very much on the degree of refinement and level of facilities required.

The simplest possible transfer station consists of an area of hard standing on which the incoming refuse is tipped, and a front-loading tractor to load it into bulk lorries. The cost of such a facility is obviously minimal, probably below £1 per tonne even for a small-scale operation, but the appearance and other environmental effects would not normally be acceptable, in urban areas at least. Such an arrangement might be established perhaps as a temporary measure at an old landfill site approaching completion.

A slightly more sophisticated plant might incorporate hydraulic packers to compress the waste into containers. The compaction would enable greater vehicle payloads to be achieved, and by using spare containers some degree of storage would be possible. A plant of this type is being constructed by West Midlands C.C. for use at an existing landfill site; for a throughput of 20 000 t/a, the estimated cost is about £3.50 per tonne, including the cost of transport to a disposal site about 15 miles away.

For a permanent plant, the capital cost will obviously be much greater than for these temporary arrangements, as a building and more sophisticated handling systems will be required. With these improvements, however, the plant becomes much more environmentally acceptable, and could be sited in an industrial or even residential area. The main

impact of such a plant would be that due to vehicle movements. The cost of a plant of this type to handle 50 000 t/a, including transport to a site 15 miles away, is about £5 per tonne.

A transfer station may incorporate some form of treatment of the waste, in addition to the basic transfer function. Having already the cost of handling the refuse, the cost of treatment may become less of an obstacle. Pulverisation in a plant regarded mainly as a transfer station is not uncommon, and some degree of material separation, particularly of ferrous metals, would seem attractive.

Instead of transferring the waste to road transport, some plants transfer to rail or barges. This would be financially attractive only for very long hauls, say over 50 miles, though there might also be environmental advantages. The cost of the plant is slightly greater than that for road transfer; the cost of the transport would obviously depend on individual circumstances. In the case of rail transport, the need to fill a train implies that only large plants would be practicable. The estimated cost for a plant transferring 120 000 t/a to rail is about £3.00 per tonne (excluding transport), as against £2.70 for a comparable plant transferring to road transport. The sophisticated plant at Brentford (Millbank (1977b)) is designed to handle 200 000 t/a.

1.4.3 Separation

In principle most of the materials in present-day household refuse could be reclaimed. The main problem in

doing this is that the refuse is a mixture of a large number of materials, each in small quantity. The cost of separating the components and transporting them to the appropriate industries is usually greater than that of extracting and transporting new raw materials. In many cases, also, the reclaimed material cannot be made identical to the original. Recycled paper, for instance, has shorter fibres than top-quality new pulp, and so cannot be used to produce certain grades of paper. However, in recent years there has been a growing awareness of the depletion of primary raw materials, which has led to demands for more extensive reclamation. The Government has expressed its support in principle in the green paper "War on Waste" (1974), and a good deal of research is being carried out in this area.

The only component of refuse which is commonly recovered by separation at present is ferrous metal. This is relatively easy to extract from refuse, using various magnetic devices, and a fairly good market for it exists. It is usually recovered at incineration plants, either from the crude refuse or the ash, and sometimes also at transfer and pulverisation plants. The additional cost of handling would rule out a plant solely for separating metals from waste, though there have been instances of the use of separators at landfill sites.

In the past, many refuse treatment plants incorporated manual separation, usually involving picking over the refuse on a conveyor belt. This was often used as a preliminary to incineration, and sometimes to composting. Such installations exist in a number of plants which are still

in operation, but in the West Midlands at least they are no longer used. The picker's job was, as can be imagined, arduous and unpleasant; labour was therefore difficult to recruit, and the operation was not economic. It is unlikely that this method will be used in any future plant.

Current research in this area is aimed at finding mechanical methods of separation, requiring as little manual involvement as possible. A good deal of work on such systems has been carried out by the Warren Spring Laboratory, and prototype plants are to be built to test their ideas in practice, in South Yorkshire and Tyne and Wear (Anon. (1975b)). The main methods used in these plants, in addition to magnetic separation, are screening (separating particles of different sizes), flotation (separating materials of different densities) and ballistic separation (separating by density and/or hardness, depending on the detailed layout). Where glass is separated from the other components of the refuse, optical sorters have sometimes been used to separate glass of different colours. A discussion of the various separation devices is given by Pavoni, Heer and Hagerty (1975).

It is, of course, possible to avoid the difficulties of separation systems entirely, by keeping the different components of the waste separate at the source and collecting them separately. This is done to some extent at present, in that some authorities collect waste paper separately, usually in a trailer attached to the normal collection vehicles. In Huddersfield an experiment in the use of much more separation at source is being conducted by Oxfam, with the co-operation of the local authorities (Millbank (1975a)). Ferrous and non-ferrous metals, glass and plastics

are recovered for recycling, and items which could be resold are sent to Oxfam's own shops. This scheme seems to be successful at present, but it involves the use of voluntary labour, not normally available to local authorities, without which the economics would be very doubtful. It is also possible that householders are more willing to help a charity (by taking the trouble to separate their refuse) than they would be to help the local authority. This approach may thus not prove generally applicable.

Most separation schemes depend for their economic benefits on the sale of the recovered materials, so the state of the market for these materials is crucial. The much publicised fluctuations in waste paper demand have been subject to a good deal of study (e.g. Turner and Grace (1977)). Consideration has been given to the possibility of encouraging industry to use reclaimed materials by some form of subsidy (War on Waste, 1974) but any such decision would be made by central rather than local government. The economics will depend on the part of the country in question, since transport costs are an important part of the cost of these materials to the user. Glass, for instance, may be worth recovering if there is a substantial local glass industry (as in South Yorkshire, for instance) but not otherwise. The results of the scheme recently initiated by the Glass Manufacturers' Federation, in which glass is collected for recycling in Barnsley and Oxford, should be interesting (Millbank (1977a)).

1.4.4 Pulverisation

Pulverisation, as its name suggests, involves breaking

up the waste input into small fragments. Generally the output particles are of the order of 10cm across, though a wide range of sizes can be produced according to the requirements. Most systems also produce a "reject" output, either by rejection from the pulveriser itself or by requiring pre-sorting of bulky unbreakable objects.

This treatment is used for a number of different purposes. If waste is to be landfilled, pulverisation will make it easier to handle and less visually offensive when deposited. Less cover will be needed because of the absence of large particles, and the settling time of the completed fill should be reduced. Some people also believe that the risk of water pollution is reduced, but this point is disputed.

Pulverisation is also used as a preliminary to other forms of treatment. In a separation plant, it can help to separate the different materials in objects made of several different kinds of material. It is essential before composting, most forms of pyrolysis and one method of baling, and is also used in the production of refuse derived fuel and some experimental methods of incineration.

There are two distinct methods of pulverisation, usually referred to as the "wet" and "dry" methods. In the wet system the refuse is fed into a long horizontal (or slightly inclined) drum, which rotates slowly on its axis, and wetted with water or sewage sludge. The tumbling action breaks up the particles, and when they reach the desired size they fall through holes in the drum and are removed. Elaborations of this system can produce several different sizes of output particle at once, a feature which is sometimes useful.

This method has the disadvantage of producing wet output, which obviously makes it unsuitable for pre-treatment of waste destined for incineration or other thermal treatments, and undesirable where the waste must be transported after processing (because of the increased weight). It is best suited to composting or local landfill applications.

The dry method involves a set of hammers attached to a rapidly rotating shaft inside a casing, which may incorporate anvils. The refuse is broken between the hammers and the anvils or the casing, and falls to the outlet at the bottom of the machine. In some versions, large unbreakable objects are automatically thrown into a reject chute by the action of the hammers. The main problem with operating this type of plant is the need for frequent maintenance of the hammers, which wear and must be retipped or replaced. The plant is fairly noisy in operation, though it causes no other problems. The cost of such a plant is about £3.40 per tonne.

1.4.5 Baling

In this process, the waste is compressed under high pressure into bales of about 1m^3 final volume, which weigh about a tonne. In some versions the bale is self-sustaining (though it expands to some extent immediately after production), whereas others require the bales to be bound with wire after compression. Some systems also require the waste to be pulverised before baling. It is important to note that this form of treatment was developed for use with unsorted domestic waste, and there is some question as to whether baling would succeed if some materials (such as paper) were separated.

The bales produced are much easier to handle than refuse - they can be moved by a fork-lift truck and carried on flat-bed lorries. The latter point should mean that transport costs would be reduced. Landfill is the only way to dispose of the bales, but the site would be much easier to manage than conventional landfills, since the bales need only be stacked together. The visual impact, and such problems as blown paper, should be much reduced, and it is claimed that water pollution is less likely, though at present there is no experience to support this.

A baling plant is being constructed in Glasgow which will be the first in the U.K. (Millbank (1976d)). The cost of treatment is estimated at £4.70 per tonne. The plant would also in effect provide a transfer station, and the transport costs should be even lower than with bulk refuse, because simpler lorries can be used. Savings in transport cost can thus be offset from the cost of processing.

1.4.6 Composting

The composting process deals with the biodegradable fraction of refuse, by allowing it to decompose under controlled conditions to produce a saleable compost. The incoming refuse is pulverised, and usually inert materials are separated as far as possible. In the simplest systems the refuse is then allowed to decompose in windrows, and turned at intervals until the process is complete. More elaborate methods accelerate decomposition by mechanically agitating and aerating the waste. The process is described in detail by Davies (1961).

The main problem with this process is to find a market for the compost. For agricultural purposes it is usually unacceptable because of its relatively high heavy metals content, and the risk of contraries such as glass or plastic being included which might endanger animals. Also, the cost of transporting the compost is high compared with that for concentrated synthetic fertilisers. It is possible to landfill the compost, but for this purpose it has little advantage over pulverised refuse and costs more to produce.

Because of this basic problem there are few composting plants now operating, though the Leicester plant seems to be successful (Millbank (1976c)). It is considered unlikely that any new composting plants will be built in this country - though they may be attractive for developing countries, where the needs are different.

1.4.7 Incineration

Incineration is a very versatile technique which, in different forms, can be used to treat a wide range of wastes. The description here will concentrate on its application to domestic-type waste, but it is also used to deal with some difficult industrial wastes, for which the details of the plant will be very different. Because of the variety of such wastes which may need to be dealt with, and the resulting variety of techniques, no attempt will be made to consider this area of use. A discussion of incinerator design for various applications is given by Corey (1969).

The effect of incinerating domestic-type refuse is to produce a large quantity of waste gases, a much smaller amount

of ash or clinker, and heat. The gases are mainly carbon dioxide and water vapour, both of which are relatively harmless and anyway result from burning all common fuels (so the effect on the atmosphere of an incinerator in an urban area will be small compared to that of the other sources). Some components of refuse do produce more harmful gases when burnt; the best-known problem in this respect is with PVC and other plastics containing chlorine, which when incinerated produce chlorine and hydrogen chloride gases. In quantity these would be serious pollutants, but the present content of such plastics in refuse is so small that they are usually unimportant. In the past, incinerators have caused serious local pollution by the release of substantial quantities of dust and paper char with the exhaust gases, but modern plants incorporate electrostatic precipitators to clean the gases, and with this provision the results are acceptable. Unlike large furnaces burning coal or oil, incinerators do not present a problem of sulphur dioxide pollution, because the sulphur content of refuse is low. A plume of steam is produced, which may cause visual offence, although it is physically harmless.

The ash produced should be inert, and should have only about 30% of the weight of the crude refuse, and about 10% of the volume. In practice the results depend on the operation of the plant, particularly with the older batch type. In the past the ash was often sold for some use such as the production of building blocks, and the output from a well-run modern plant may be suitable for use in road construction (Roe (1976)), but the normal practice at present is to landfill the ash, perhaps as cover for crude refuse.

It has a high content of heavy metals, but these should be in insoluble forms, and it is generally regarded as an easy material to use for landfill. Indeed, the view has been put forward that the use of residue as a cover for crude refuse landfills is a positive advantage, because its rather alkaline nature will tend to neutralise the more acidic refuse leachate (Millbank (1976f)). On the other hand, a wide range of ions have been found to leach out of residue over long periods; residue is by no means inert (Schoenberger and Purdom (1976); Schoenberger and Bender (1976)). Although there may be doubts in this respect, there is no question that incineration does greatly reduce the volume of landfill space eventually required, and the process has been widely used by those authorities which have difficulty in finding suitable sites for landfill - mostly the large cities.

In most incinerator plants in this country the heat produced is treated as a waste and dissipated to the atmosphere. In principle this energy could be used, and there are a few plants in Britain, including that at Coventry, where this is done (Millbank (1977c)). The heat may be used as such, to heat houses or as industrial process heat; or it may be used to generate electricity for the National Grid. Another possibility is to dry sewage sludge, so that it can be incinerated in the plant. Unfortunately these ideas, though attractive in principle, are difficult to put into practice. The capital cost of the additional plant for recovering the heat is substantial, and most installations have suffered from corrosion and erosion of the boiler tubes, which causes additional maintenance costs (Anon. (1977)). Consequently, heat

recovery cannot at present be justified purely on economic grounds.

Early incinerator plants used multi-cell fixed grate furnaces, usually to deal with the tailings from a manual separation line; this type of plant is thus usually referred to as separation-incineration. This form of plant is no longer built, though there are a number still in use. More modern plants have been designed to incinerate the refuse directly, without separation; ferrous metals are usually reclaimed from the ash. These direct incinerators use moving grates of various designs, which turn the refuse to ensure that it is thoroughly burnt and move it along the grate from the feed point to the ash removal point.

Both the systems described above involve the construction of a large plant (for economic reasons) with a tall chimney. A new form of incineration has been devised in the USA which is claimed to avoid this, thus reducing capital cost and making small plants economic. This system, known as modular incineration, involves the use of small grateless furnaces, which are claimed to operate in such a way that no cleaning of the output gases is necessary. Large plants can be built by using a number of the furnaces (hence the term "modular"), but it might be preferable, if this system were adopted, to have a number of smaller plants, thus reducing transport costs. There are no plants of this type in this country at present; the system is described by Millbank (1975c).

The cost of a new direct incineration plant is estimated at £10 per tonne. Experience with the plants in the West Midlands shows that these plants are rather

unreliable, with a long-term availability of about 85% being the best achieved overall. To cater for the maintenance or unexpected breakdown of the plant, it is essential to have an alternative disposal facility available. Modern plants have large input bunkers, which can store as much as three days' normal input, but these may not be empty at the time of breakdown, and some repairs may take as long as several weeks.

1.4.8 Refuse Derived Fuel

Instead of constructing special incineration plants to burn refuse, it is possible to prepare it so that it can be burnt in conjunction with other fuels (most commonly coal) in a conventional type of furnace, for instance an industrial power station. Several experiments with this approach are now in progress in this country, and are showing encouraging results.

One example is the scheme at the Imperial Metal Industries (IMI) works at Witton, Birmingham, where refuse derived fuel (RDF) is being used to replace up to 50% of the coal used in a power plant (Millbank (1976a), Marshall and Harvey (1977)). The RDF is prepared by the company from crude refuse and blown into the furnace above the grate. So far there have been no problems with the gas cleaning or ash handling equipment; the ash is sold for making breeze blocks, and has caused no difficulties.

Another experiment is at the Associated Portland Cement Manufacturers plant at Shoreham, where RDF is being used in cement kilns (Millbank (1976b)). Here the ash

is incorporated into the product; the preparation is again carried out by the company.

To produce RDF the crude refuse is pulverised and ferrous metals separated. Glass and other inert components may be separated but this is not essential (it is not done at IMI, though provision has been made to add it later). The fuel value comes from the organic, paper and plastic materials. This is a very convenient way of dealing with the tailings from a separation plant, and both the experimental British plants (see sec. 1.4.2) will use it. In the IMI project, the cost to the County Council is £2 per tonne; this is less than the processing cost, but presumably reflects the cost anticipated by IMI, taking into account the fuel saving. This is very much lower than the cost of conventional incineration, with the added advantage of energy recovery. If the experiments continue successfully it seems likely that this will be a very attractive system for future use.

1.4.9 Pyrolysis

Pyrolysis as a refuse treatment is a recent development, first proposed in the USA. There are at present no full-size plants in this country but the Warren Spring Laboratory is testing the process on a laboratory scale. The refuse is heated in the absence of air, producing a distillate from which an oil can be condensed. Gas and char are the other products; the relative proportions depend on the exact conditions of the reaction. Both oil and gas are usable as fuels, so the process recovers energy from the waste. Some heat input is required to maintain the reaction, but this can be obtained from part of the products.

There are a number of processes being developed under this heading, each with slightly different characteristics. Most require the refuse to be pulverised before treatment, and inert materials to be separated. It is expected that full-scale plants will resemble incinerators, though without the large chimney and potential air pollution of an incinerator. The cost is also expected to be comparable to that of incineration; the economics of the idea depend on the market for the products which at present is unknown.

1.5 Deposit of Waste on Land

Whether or not some form of treatment is used, most waste will eventually be deposited on land. This can create hazards or nuisances if not properly planned and controlled, and such problems have often arisen in the past. It is to be hoped that the site licensing provisions of the Control of Pollution Act 1974, now coming into force, will ensure that these problems are avoided in the future. If a landfill site is well selected, prepared and operated, its drawbacks can be outweighed by the benefits available from the reclamation of the land. For instance, large disused quarries can be filled with waste when it would be uneconomic to use other fill materials. This positive result of landfill has led some people (e.g. Bevan (1974)) to regard landfill as a desirable form of waste disposal, and oppose the traditional view that its only advantage is financial. Obviously if such voids are to be filled without creating similar new ones elsewhere, waste is the only material available (the holes created by its production will exist anyway).

Apart from the problems usually associated with large civil engineering projects, the difficulties of waste landfill depend on the type of waste being dealt with. There may be more opposition from local residents to a project described as a waste disposal site, rather than (say) construction of playing fields; but the strength of the protest will depend to some extent at least on the nature of the waste.

There are many wastes, probably the majority in total tonnage, which are essentially inert, and in most respects can be treated in the same way as other types of aggregate. Power station ash or demolition rubble, for instance, would fall into this class. There may be more difficulty in handling these materials than is found with "new" fill (i.e. material extracted specifically for use as fill), but the amenity effects should be similar. Unlike projects using new aggregates, waste landfill sites will normally have no control over the supply of material; at best, it may be possible to control the input to some sites of a group at the expense of greater variation in that to others. This may present an additional operational problem.

Much greater difficulties arise when a biodegradable waste such as household refuse is to be deposited. There are potential health hazards; refuse attracts insects and vermin, which could breed in large numbers on a landfill site and spread disease. Also, there are amenity problems such as smells and paper carried from the site by the wind. However, these problems can be overcome by suitable operation. The system known as "controlled tipping" or "sanitary landfill"

has been developed over many years for dealing with household refuse, and most authorities regard the results achieved by its proper application as satisfactory (see, e.g. Sumner et al. (1971), ch. 5; but note the reservations of Marriott and Oates).

The main operational precautions in controlled tipping are that the refuse is deposited in layers, not more than about six feet thick, and covered with an inert material as soon as possible, and in any case within 24 hours. A bulldozer or front-loading tractor is normally used to handle refuse on the site, and this will run over the layer of refuse deposited, compacting it and crushing any voids which might harbour vermin. Prompt covering of the refuse will prevent it from attracting insects, and also make it difficult for larvae brought in with the refuse to escape, if necessary, chemical insecticides can be used. The cover will also reduce the problem of smell from the tip, and its visual impact. Wind-blown paper can be controlled by proper fencing of the site, which is needed in any case to prevent children playing there. A full discussion of the operation of controlled tipping, and the effect on the refuse after deposit, is given by Bevan (1967); he also includes descriptions from a number of local authorities of their experience.

As well as care in operation, careful selection and preparation of the site is needed if controlled tipping is to be satisfactory. As the term "landfill" suggests, the most common choice is to fill a hole in the ground, either one produced by the extraction of minerals or, less often, a natural valley. Sometimes controlled tipping is used to raise the level of low-lying ground such as marshland, making it suitable for more intensive use. The site should be dry,

as tipping refuse into water is known to cause smell and possibly other problems. It should preferably be well clear of residents - Sumner et al. (1971) recommended a minimum of 200 yd. Preparation should always include fencing, and the provision of good access to the site. Streams crossing the site can be culverted, if such a site must be used. It is rare to find a weigh-bridge installed on a landfill site, but clearly this is a useful facility for monitoring the rate at which the site is filled, as well as providing information on the refuse arisings in the area. (In contrast, a weigh-bridge is almost always installed at an incinerator - perhaps the low-cost image of landfill is responsible for this economy).

A most important consideration in site selection is the possibility of polluting water supplies. Even if a site without surface water is used, there will be rain falling on the tip, and in most parts of Britain there is appreciable net rainfall (i.e. precipitation minus the proportion which evaporates immediately from the ground). This water will percolate down through the waste, and with biodegradable or toxic wastes the leachate may be very polluting. Unless this is stopped by some impermeable stratum such as clay (or a deliberately constructed impermeable layer at the base of the tip) it will percolate down to the water table, and may pollute the groundwater. There is also the risk that the surface run-off from the site, which is also likely to be polluting, may enter streams.

Because of this danger to water supplies, it is important to consider the geology of potential sites.

There is some reason to believe that most of the pollutants may be absorbed by the rocks in the unsaturated zone, and thus never reach the water table (e.g. Department of the Environment (1975)), and in any case pollution of water which is demonstrably due to refuse tipping seems to be quite rare (e.g. Waterton et al. (1969); Zanoni (1972)). However, it has been suggested that modern practice, which produces a more compacted tip, is more likely to cause pollution than earlier methods (Millbank (1976e)). Under the Control of Pollution Act 1974, water authorities will have to be consulted before licensing a site, and they will need to be convinced that there is no risk to water (Morgan-Jones (1976)). There is at present a programme of research on the dangers of waste tipping, particularly of hazardous waste (Department of the Environment, 1975); guidelines for the selection of sites have been given by Gray, Mather and Harrison (1974), and by the Department of the Environment in one of their Waste Management Papers (Department of the Environment, 1976c). Summers and Spiegel (1974) give over 50 references to work on the effect of solid waste on ground water. Harrison (1976) describes a method of drilling boreholes in landfill sites to investigate the leachate.

A debate has recently arisen on the question of whether it is more desirable to prevent the escape of leachate from landfill sites altogether, or to allow a slow release of leachate in such a way as to ensure its dilution to a harmless concentration; these alternatives are referred to as the policies of "concentrate and contain" and "dilute and disperse" respectively. The former approach seems more

appealing at first, since the principles of containment are well known, unlike those of the dispersion of leachates in underground strata; on the other hand, it is difficult to ensure permanent containment, and the containment policy is likely to be much more expensive in most cases. If current studies provide sufficient understanding of the dilution mechanisms to allow judgements on the effects of a given site to be made with confidence, the "dilute and disperse" approach is likely to be widely adopted. A paper by Mather (1977), with the following discussion, will indicate the tone of the debate. If suitable sites can be found, landfill is the cheapest way of dealing with refuse, costing about £1-£2 per tonne. Since it is generally regarded as environmentally acceptable, the main reason for using treatments for refuse has been the lack of suitable sites within a reasonable distance. Treatments reduce, but do not eliminate, the need for landfill space. The volume required for a tonne of crude refuse may be as much as 2.5m^3 , compared with as little as 0.3m^3 for the residue from incinerating a tonne of refuse. However, the use of heavy tractors with steel wheels, specially built for use on refuse tips, has been found to reduce the volume of crude refuse with cover to as little as $0.7\text{m}^3/\text{t}$, making crude refuse landfill much more competitive in this respect (Briggs (1976); Bratley (1976)). Landfill is also a reliable operation, unlike some forms of treatment. However, in the long term it is possible that landfill of crude refuse will not continue to be accepted, and for urban areas especially there is also the risk that suitable sites will not become available. Nevertheless, landfill of wastes in some form, and in some parts of the country, will inevitably continue for the foreseeable future.

2. PLANNING SOLID WASTE MANAGEMENT

This chapter will discuss the problem of planning a long-term solid waste management strategy, from the point of view of the waste disposal authorities. Under the provisions of the Control of Pollution Act 1974, these authorities will be responsible for the production of a plan, in consultation with a number of other bodies (the relevant sections are not yet in force). The legal requirements, the influence exerted by central government in other ways, and the interests of the other parties to the plan will be outlined, and the way in which the authority decides on its plan will be considered.

Many waste disposal authorities, including the West Midlands County Council, have already done a good deal of work on their plans (West Midlands County Council, 1976a, 1976b). However, the requirement for planning is a continuing one; even when the plan for the immediate future is complete, there will be a need for further planning in a few years, as landfill sites fill up and policies with respect to waste develop. The plans now being prepared are the first of their kind ever produced in Britain, and it is to be expected (and hoped) that critical examination of these documents and the ways in which they were produced will lead to the use of improved methods for the next generation of plans.

2.1 The Requirements of the Law

The Control of Pollution Act 1974 introduces a comprehensive requirement for waste disposal authorities

to plan waste management within their areas. Section 1 begins "It shall be the duty of each disposal authority to ensure that the arrangements made by the authority and other persons for the disposal of waste are adequate.....". Section 2 details the planning required:

- "(a) to carry out an investigation with a view to deciding what arrangements are needed.....;
- (b) to decide what arrangements are....needed....;
- (c) to prepare a statement of the arrangements made and proposed.... (hereafter....referred to as "the plan");
- (d) to carry out from time to time further investigations with a view to deciding what changes in the plan are needed....
- (e) to make any modification of the plan which the authority thinks appropriate...."

They are required to consider the effect on amenities and the cost to themselves of any arrangement or modification.

Requirements are also laid down as to the information which is to be included in the plan (section 2(2)):

- "(a) the kinds and quantities of controlled waste which the authority expects will be situated in its area during the period specified in the plan;
- (b) the kinds and quantities of controlled waste which the authority expects to be brought for disposal into or taken for disposal out of the authority's area during that period;
- (c) the kinds and quantities of controlled waste which the authority expects to dispose of itself during that period;

- (d) the kinds and quantities of controlled waste which the authority expects to be disposed of.....by persons other than the authority;
- (e) the methods by which.... controlled waste in its area should be disposed of....and the priorities which....should be accorded....to the provision of different methods of disposal;
- (f) the sites and equipment which the authority and other persons are providing....;
- (g) the estimated costs of the methods of disposal mentioned...."

Provision is made for regulations to alter these requirements, but the above seems to be a good basic list of the objective information which might be included. Matters such as amenity effects and pollution problems are at present much harder to quantify, or evaluate in an objective way; authorities might therefore be reluctant to provide information on these points, which might reasonably be challenged by outside interests. (While cost estimates particularly for new facilities are subjective to a large extent, these are perhaps less likely to be challenged). However, it seems desirable that such information should be made public so that proper consultation can take place.

Section 2(3) lays down requirements for consultation with other bodies and the general public before the plan is regarded as final. The waste disposal authority is specifically required to consult the relevant water authorities, collection authorities and any other disposal authorities into whose areas waste is to be taken for

disposal (in this last case the consent of the other authority or the Secretary of State for the Environment is required), and also representatives of the private waste disposal industry in the area. The plan must also be publicised within the area of the authority, and members of the public must have the opportunity to make representations to the authority about it. A specific duty is imposed to consult with anyone whom the authority considers appropriate, to consider possible arrangements for reclamation.

Although the water authority cannot prevent any proposals being included in the plan, it can withhold consent for the licensing of the sites involved, under the other major new provision of Part I of the Control of Pollution Act. The other bodies involved in consultation appear to have no sanctions provided by the Act to support them if the waste disposal authority decides to ignore their advice. Since the council is an elected body, however, it seems unlikely that a proposal which attracted extensive public opposition would be accepted in the plan.

2.2 The Interests of Outside Groups

There are a number of groups outside the waste disposal authority whose interests are affected by the decisions made in preparing a waste disposal plan, and who will seek to influence these decisions. These groups include those listed above for consultation in the course of preparing a plan; in addition, the central government will have some indirect influence, as well as that exerted through legislation, and the owners of land in the area suitable

for waste disposal activities will have an interest and an influence, whether or not they are (or intend to be) involved in such activities themselves. Although in the consultation requirements "the public" was referred to as a single body, in practice there will be a number of different groups putting forward views under this heading, representing both general opinion from some sections of the public (from environmental groups like the Friends of the Earth) and the reaction of local residents to specific proposals (from groups such as Resident's Associations, or ad hoc organisations).

The water authorities are of course concerned with the protection of water supplies; in practice this means that their interest in waste disposal is largely in connection with landfill sites (though treatment plants often produce very polluted effluent, it can be handled like other industrial effluents). They will require thorough investigation of the geology of proposed sites, to ensure that they will present no threat to groundwater. Since the criteria for a site's geology to be safe are not well established, there is perhaps some risk that the water authorities will be unnecessarily cautious in their decisions; it will of course not be possible to tell whether or not this has been the case until the criteria are determined.

The collection authorities will be concerned to ensure that the plan will not place excessive demands on the collection service, by requiring collected waste to be transported long distances to disposal points. Despite the provisions for compensating payments from the disposal authority, a sudden increase in the time spent transporting

refuse to disposal would be difficult to achieve without re-organising the collection system and so would not be acceptable without considerable advance notice. Although the allocation of disposal sites to collection rounds need not be specified in the plan, it must be considered in order to determine the cost to the waste disposal authority of the compensating payments, and the cost of the proposed arrangements to the authority must be considered. In some areas, also, there are "agency" arrangements in use, whereby the disposal sites are operated by district council staff, the collection authority acting as agents of the disposal authority. In such cases the county has only a minimal waste disposal staff, and the preparation of a plan would clearly require the local knowledge and practical expertise of the district staff.

When disposal sites outside the authority's own area are to be used, it will clearly be necessary to have detailed discussions with the disposal authority responsible for each site, so that the proposals can be integrated into that authority's waste disposal plan. For most types of waste, this is likely to involve groups of adjacent authorities; it is especially likely to be needed around the major conurbations, which will have difficulty in finding sufficient landfill sites within their own boundaries and so will turn to the surrounding rural counties. Some hazardous wastes, however, are at present being transported over much greater distances to the very few sites in the country which will accept them, and authorities with such sites in their areas may wish to restrict this traffic in future. This seems likely to be the case, for instance,

at the Pitsea site in Essex (Anon. (1974); Potter (1975)). Thus, although consultation on a regional scale will be adequate for most types of waste, national discussions will probably be needed on sites for the disposal of toxic wastes.

The private waste disposal industry is not a homogeneous group, but includes firms specialising in transport, landfill, and various forms of waste treatment, and others which carry out combinations of these activities. Thus the industry does not have a single interest; some firms will have an interest in policies encouraging the use of crude landfill, others in those favouring treatment, others in those tending to lead to the use of large centralised facilities and thus greater need for transport. It seems likely that the greater degree of control, and higher environmental standards, which will be demanded will be welcomed by the larger and more reputable companies, as tending to improve their competitive position with respect to the smaller operators, whose standards in the past have often been lower (see, e.g. Millbank (1975d)).

Apart from legislation, and regulations made under powers conferred by legislation, the central government has two main ways to influence the decisions of local authorities; it controls a major source of finance, and it issues advice which is generally regarded as authoritative. Detailed control of expenditure is not practised, at least in the field of waste disposal, but at present there is strong pressure on all local authorities to reduce their spending in general, so that expensive schemes, no matter how desirable in other respects, are unlikely to be undertaken at the moment. In the case of capital expenditure, waste

disposal is not included among the "key sector" areas of major expenditure, which require detailed approval of schemes by central government. The sums allocated for other, "locally determined schemes" are however smaller than those for the key sectors, and a major treatment plant, for instance, would require the commitment of a large proportion of the locally determined expenditure for several years. Some schemes of a partly experimental nature, which are regarded as in the national interest but too risky for a local authority to undertake alone, are given special financial assistance (e.g. the mechanical separation plants now being built - Anon. (1975b)). For general information on local authority finance, and other aspects of the relationship of local to central government, see Redcliffe-Maud and Wood (1974, chs. 8 and 9).

The advice issued to local authorities by central government includes both guidelines on general policy, such as the green paper "War on Waste" (1974), and detailed technical recommendations like those in the series of Waste Management Papers (Department of the Environment, 1976a,b,c). "War on Waste" is a good illustration of the difficulties of advising on general issues; its support of reclamation and waste reduction policies is so heavily qualified as to be almost meaningless. The decisions to be taken are in the last resort political, so clear recommendations would be too contentious to be published. Technical advice, on the other hand, can be sufficiently authoritative to overcome any reservations felt by the officers of most local authorities - there are few counties which employ staff with sufficient experience and knowledge to assess all the available disposal methods for themselves,

or to forecast the waste arisings accurately from local information. The availability of such advice does tend to discourage local authorities from appointing such staff, and also encourages uniform practice across the country, irrespective of local circumstances. The more major advice documents, such as the report of the Working Party on Refuse Disposal (Sumner et al. (1971)), are used as reference works; the forecasts of arisings made in this report, for instance, are still widely used.

The owners of land which could be used for waste disposal are obviously an important group, but its members are hard to identify without conducting a major survey to locate all such land and determine its ownership. The main concern is with land for the permanent deposit of waste; suitable areas are usually old quarries or similar holes in the ground, whether artificial or natural. Most such sites are (not surprisingly) owned by companies interested in mineral extraction. An investigation in the West Midlands of the sites suitable for landfill located by an aerial survey disclosed that many mineral workings which appeared to be disused and abandoned were in fact only temporarily out of operation, due to the state of the market for the product; more extraction would take place at some time in the future, and the owners would be unwilling to use the site for waste disposal until the mineral deposit had been worked out. With the growing public awareness of waste disposal, and the increasing value of suitable sites, many mineral-extraction companies have formed associated firms to deal with waste disposal in the completed quarries, and it is possible that in the future the value of sites will become sufficient to encourage owners to arrange

extraction so that filling of the completed part of the excavation can take place at the same time.

Unlike the groups considered above, the general public have no economic influence on waste disposal (except by the changes in quantities of various materials thrown away by households); their power in the decision-making process is entirely political. National "environmental" groups such as the Friends of the Earth conduct general campaigns on issues such as the re-use of glass bottles, and usually support local groups in voluntary recycling activities. The local branches may seek to influence waste disposal plans by political means, in favour of the options which they regard as more desirable environmentally (usually recycling in one form or another). The support (in principle) of central government for such views has been expressed in, for instance, "War on Waste" (1974) as well as in special provisions in the Control of Pollution Act 1974; however, these questions do not yet seem to be major issues in local politics, so the actual influence on long-term strategy of such groups seems doubtful. The only clear exception is the Oxfam project in Huddersfield (Millbank (1975a)), where a voluntary organisation is working in co-operation with the local authority.

The position of local resident's associations and similar organisations seeking to influence decisions about their particular part of a county seems to be politically stronger, perhaps because the electoral system is such that a group which is geographically concentrated has a definite member of the council as its representative, unlike a group which is spread thinly throughout the area. The disposal of waste by controlled tipping, in particular, has

a poor public image and is likely to be opposed by those who live near a proposed site, but the construction of a major treatment plant would also have some effect on local amenities, particularly due to the traffic generated. Thus, any new waste disposal facility is likely to encounter local opposition.

2.3 The Decision-making Process in the Waste Disposal Authority

Faced with all the advice provided by the various groups referred to above, the waste disposal authority has the task of formulating the plan for waste management in its area. The authority itself, however, is a complex body with an elaborate internal structure. Some understanding of this structure is essential if the nature of the planning process in an authority is to be understood. A general discussion of local authority structure is given by Redcliffe-Maud and Wood (1974), and Friend and Jessop (1969) analyse the process of making strategic decisions in detail.

The most fundamental division in local authorities is that between the members of the council, who are elected and unpaid, and the council officers, who are full-time employees of the council. In principle, the division of activities between these two groups is that members are responsible for "policy" decisions, and officers for "technical" or "administrative" ones. This is interpreted by Simon (1976) as a distinction between judgements of value and judgements of fact; as he points out (p. 52), "the separation between the ethical and the factual elements in judgement can usually be carried only a short distance". It is accepted in practice that the distinction is not a clear-cut one, since all decisions involve both aspects; the essential point is that members make all major decisions,

with the advice of the officers, who then apply these decisions as best they can. The implementation naturally involves decisions as to which of a set of possible actions best expresses the council's intentions; collectively, these small decisions have a major effect on the effective policy (as distinct from the stated policy) of the council.

As well as this division according to forms of responsibility, there is a division according to areas of responsibility - the members being members of one or more committees as well as the whole council, and the officers being employed in a particular department. Committees and departments may be responsible for particular services to the public provided by the council (such as education), or for particular fields of activity which amount to internal services (such as finance). Redcliffe-Maud and Wood (1974) refer to these as "vertical" and "horizontal" divisions respectively. The divisions of committees and departments do not necessarily correspond.

In most English counties, waste disposal is dealt with by the engineer's or surveyor's department, though there are a few cases (including the West Midlands) where there is a separate waste disposal department. However, because of the existence of horizontal as well as vertical areas of responsibility, and perhaps more importantly the "corporate management" approach to major decision-making, other departments are necessarily involved in the production of a waste disposal plan. The reports on the preparation of a waste disposal plan produced by the West Midlands County Council (1976a,b) were formally signed

by the Chief Executive on behalf of all chief officers; and although much of the work for these was done by staff of the Waste Disposal Department, there were contributions from other departments, and the initial version was edited by an interdepartmental working group. This group has been set up semi-permanently to deal with the preparation of the W.M.C.C. Waste Disposal Plan, which will not be completed until the implementation of the relevant sections of the Control of Pollution Act 1974.

Apart from the specialist waste disposal officers, those most directly concerned with the preparation of the plan are the long-term planning officers of the treasurer's and planning departments. The planning department of a county is responsible for major land use planning decisions and the preparation of the county structure plan, although the districts have powers to deal with local decisions - the exact separation is not entirely clear and may be a matter of dispute. However, county planners would certainly be involved in the choice of a major landfill site, for instance, since this affects the possible use of the land for some time after the completion of filling - sites are normally used as open space for many years after the completion of a domestic refuse tip (if indeed they are used at all). Sometimes, where an area of derelict land is to be reclaimed and fill material is required, the planning department might propose the use of waste material, though in the past this has been rare.

The treasurer's department is responsible for obtaining estimates of future expenditure, allocating budgets and monitoring the spending of the sums allocated. Their main interest is thus in the cost of a plan to the authority;

because money is always in short supply (though more acutely at some times than others), and there are many other worthwhile projects on which it could be spent, they will seek to reduce the cost of the plan to the minimum compatible with acceptable standards of operation. Since "acceptable standards" are to some extent subjectively determined, this can cause friction with the technical staff in waste disposal, who are inevitably involved in estimating the costs of plans and assessing their acceptability. It should be noted that the day-to-day financial operation of the waste disposal service is carried out by waste disposal rather than treasurer's staff, so even for existing plants and other activities the costs are assessed by the waste disposal officers.

With a decision of the magnitude of a strategic plan for waste management, the final decision must be made by the elected members of council, either in the appropriate committee or in a full council meeting (depending on the policy of the council on such issues). Because of the overwhelming complexity of the choice and the technicalities involved in assessing the effects of a decision, however, they will need a great deal of assistance from the officers. A document will be prepared (probably, as in W.M.C.C., by an interdepartmental group of officers), setting out one or a few of the possible alternatives which the officers responsible regard as the best, and describing the effects of these alternatives in as much detail as is practicable. In preparing this set of alternatives, the officers will of course have regard to previous decisions of the council in this area, so that the proposals are likely to meet with approval. Consultations with some elected members, at least with the chairman of the appropriate committee,

will probably be needed to resolve difficult points in the course of preparing the report.

Friend and Jessop (1969) analyse the way in which the decision mechanism operated in Coventry City Council (before local government re-organisation) in terms of the operation of departments, committees, party groups and so on (ch. 3); they go on (in ch. 4) to examine the operation of the whole system, and identify three forms of uncertainty which make decision-making difficult. These are uncertainty about the environment and its response to possible decisions, about the decisions which will be taken in related fields of choice and about the value judgements to be made in comparing the effects of various possible decisions. This classification cuts across the boundaries previously discussed; the environment, for instance, includes financial, technical, social and political consequences of decisions, some of which will be assessed by the officers of various departments and others by the members of council. Since none of these forms of uncertainty can be entirely eliminated, however long is available for making the decision (and often the time allowed is very short), this analysis leads to a view of planning as a continuing process rather than a once-for-all job. There is no possibility of a final solution to planning problems; the published plan can be no more than a progress report. Though at first sight this may appear to be a negative conclusion, recognition of it allows the conditions assumed in making a decision to be stated explicitly without detracting from the value of the decision. This then

makes it possible to recognise when changing conditions require modifications to the plan (as envisaged for waste disposal plans in the Control of Pollution Act 1974), and may make it easier to decide what changes are needed. With a plan whose limitations are not specified, there may be no warning that the plan is not operating as intended.

Some of the decisions made in a waste disposal plan are to some extent irrevocable - if a new treatment plant is built, for instance, the authority may not be committed to use it (though not to do so might be politically embarrassing) but it is committed to pay for it. For major decisions of this kind, there is a natural desire on the part of the decision-makers to reduce the uncertainty as far as possible, by postponing the decision until the last moment. This tendency to "keep one's options open" is another point in favour of the continuous, as opposed to the one-off, view of planning. Caplin and Kornbluth (1975) point out the importance of this consideration in major planning problems. The planning system adopted, therefore, should not require decisions to be made all at once that could otherwise have been spread over a number of years and made with better information at the time they were needed. It is often tempting to try to make a master plan and stick to it, either because temporary staff or consultants are being used to carry out the work, or because the use of some formal methods of planning (described in the next chapter) requires this approach; the temptation needs to be resisted if the most satisfactory results are to be achieved.

3. THE USE OF OPERATIONAL RESEARCH IN STRATEGIC PLANNING

In this chapter the basic concepts of operational research and related activities will be introduced, with particular reference to strategic problems such as the preparation of a waste disposal plan. The advantages and disadvantages of using such techniques will be discussed, and various possible applications to waste disposal planning will be considered. Later chapters will examine some of these possibilities in more detail.

Operational research is one of a number of terms (others being management science, systems analysis, decision analysis, etc.) which are often used interchangeably referring to closely related and overlapping fields. I shall refer to operational research (OR), meaning the use of scientific techniques in management decision-making. I shall not attempt to define "scientific"; the main techniques referred to are analysis (asking "how does it work?", taking a complex problem apart into simpler components) and analogy (asking "what is it like?", comparing an unfamiliar problem to one that is already familiar). Particularly for those who use the "systems analysis" label, another important approach is the synthetic (asking "what does it do?," relating the problem under study to the wider system of which it forms a part). For a general introduction to OR, see Rivett (1968); Catanese (1972) is more directly relevant to the present area of application.

A related technique which must receive some attention is cost-benefit analysis, which according to Prest and Turvey (1965) "implies the enumeration and evaluation of all the

relevant costs and benefits". As Newton (1972) points out, OR has tended to concentrate on a later stage in the decision process, assuming all the costs and benefits to be known, but "the inevitable merging of the two spheres of interest....is already well advanced". In solid waste management planning in particular, one of the major problems with the use of OR methods seems to be the lack of data on most of the effects of a project - this will be discussed in detail later. The techniques of cost-benefit analysis are discussed by Mishan (1971).

The central (though probably not the most time-consuming) act of the scientific approach is the creation of a theory, or model - the latter term is more usual in OR. The model consists of a set of assertions about the situation under study. If it is to be of any use, it must be fairly general - some of its assertions must relate to questions which have not been answered previously. Not all its predictions need be true; a model whose predictions are very approximate will often be useful, and one whose predictions are sometimes wildly wrong is acceptable so long as the boundaries of its usefulness are known. For instance, to say that the cost of disposing of waste at a particular landfill site is £1 per tonne implies a model in which the cost of operating the site is proportional to the quantity of waste dealt with. If only one tonne of waste per week were delivered to the site, the operating cost would be much more than £1 per week - but this does not invalidate the model, so long as it is appreciated that it does not apply to all possible rates of use of the site.

Because those who use the scientific approach are usually accustomed to abstraction and symbolism, and the

questions tackled in this way usually lend themselves to such techniques, the models produced in OR are nearly always mathematical, in the sense of being abstract and symbolic. They usually involve at least some numerical features, since numbers are among the most generally useful and easily manipulated symbols (to those who produce the models, at least). Other forms of model might well be useful in planning - a physical scale model, for instance, could help to assess the visual impact of a proposed landfill site - but the mathematical model is almost inevitable in OR work.

3.1 Advantages and Disadvantages of Mathematical Models in Planning

The construction and validation of a good model will involve a substantial amount of work, and there is no point in undertaking this if the results could be obtained more easily in another way. Thus models are used in practice to obtain information which would be difficult or impossible to acquire directly. For instance, it is impossible to measure the quantity of waste which will be collected next year, so if we want to know this, a model of the waste production process will be needed to predict it. Similarly, it would be unacceptably slow and expensive to experiment with the allocation of collection rounds to disposal sites, in order to find the cheapest arrangement; a model of the costs would allow the experiments, in effect, to be carried out on paper or in a computer, quickly and cheaply.

A formal mathematical model for use in decision-making is often very complex, in order to deal with a complex problem, but the use of modelling is not restricted to complex situations. In fact, the simplest models are usually

the most important - but they may be so basic that they are not recognised as models at all. For instance, saying "we deal with a million tonnes of waste a year" implies a model in which the quantity dealt with does not change from year to year (otherwise the statement would have been "a million tonnes last year" or something like that), which is a very simple forecasting model. It is useful to state models like this formally, since they may otherwise pass unrecognised, even when wrong. Indeed, a very valuable side-effect of constructing a large mathematical model of a problem is that it will demand formal statements of the assumptions to be made. The formulation of these statements sometimes has more impact on the decision-makers' thinking than the results produced by the model.

The formal, general character of mathematical models in particular is also valuable in that it enables a very wide range of problems to be represented by a single model. Linear programming and its developments, for instance, can represent most resource allocation problems well enough to be useful. The few basic models can thus be highly developed, along with the techniques for manipulating them; because they are symbolic and abstract, they can easily be reproduced and modified to suit a particular problem.

One of the reasons for wanting a model of a problem situation which is sometimes mentioned by some decision-makers is to provide justification for their decisions; they feel that the use of a model, based on an OR analysis of the problem, will result in a more "scientific" or "rational" decision. This is a rather dangerous view; particularly

when a lot of effort has been invested in a model, it is tempting to assume that its results must be superior to any intuitive judgement, and to accept, without question, even conclusions that look quite wrong, but this tendency must be resisted. These are not models in the sense of "standards of excellence", but imperfect copies of reality. If an experienced manager feels that the model is wrong, to tell him that his views are "unscientific" is unlikely to change his mind, and may cause him to reject other conclusions from models which are valid. This reaction is encouraged by the fact that the models are usually produced by an independent group of OR workers, who have an interest in the use of models in decision-making.

Higgins and Finn (1976) suggest that senior managers (referring to private industry, but the same is probably true in the public sector) are doubtful about the use of models because they feel that the model neglects important, but non-quantifiable, factors, and includes forecasts and estimates which are unreliable; they therefore treat the results of models with some caution, and do not always implement the recommended course of action, but this does not mean that the models were of no use. It must be accepted that models cannot at present represent the complexity of the decision-making process described in chapter 2, and their results can only be one of the influences on the final decision. As Wilson (1977a) puts it, the model must not be a "black box" for producing plans - it is an aid to the decision-maker rather than a replacement for him.

It may be fair to say that the plans produced with the aid of a model will be more rational than they would otherwise

have been, if the word is used in a sense akin to that of game theory, where the main feature of a rational player is complete knowledge, of the results of his actions and his preferences between them (Luce and Raiffa, (1957)). A properly documented model should certainly provide clear information on these points; this may well make criticism (particularly on the preferences) easier rather than harder, compared with intuitive decisions, but it should also mean that the decisions reached are "better" in the sense that they are nearer those which would be reached with perfect information.

3.2 Applications of Models to Planning

There are a number of different ways in which models can be used to assist in the planning process. This section will attempt to indicate and classify these possibilities; later chapters will discuss in more detail the models used in the particular areas dealt with.

As noted above, models are used to obtain information which is not otherwise available. Ultimately, the information required is an answer to the question "what is the best thing to do?", but the preceding section argues that we cannot in practice specify what we mean by this question sufficiently well to use a model and rely on the results. The nearest approaches to an overall decision model that seem to be practicable are to ask either "what are the results of doing this?" or "which of these choices will be best in this respect?". Models of the first type are referred to as simulation models, and explicit simulation is often found where the problem involves probabilities, rather than events which are certain; those of the second type are called optimisation models, and are commonly used

to find a minimum-cost or maximum-profit policy, with some simple criteria for acceptability of the other effects.

These overall decision models usually require a good deal of information, some of which may itself have to be obtained using models. A long-term planning model will, for instance, require information on the quantity of waste which will arise in each year of the planned period, which will be obtained from a forecasting model, and on the costs of the various activities undertaken, which will require a costing model. Both these types of model will be discussed in detail later. Another possibility, which I have not pursued, is the use of a model to estimate environmental effects - for instance, the probability of groundwater pollution from a landfill site. These subsidiary models are not decision models, in the sense that they do not include any variables representing the decision to be made. The use of the term "forecasting" or "estimating" rather than "deciding" indicates that the decision-maker is assumed to have no control over the result referred to.

With the complex organisation for decision-making described in chapter 2, it is clear that there can be no single, central decision-maker; the various groups involved must, to some extent, operate in competition, and decisions must be taken without knowing what some other decision-makers have decided or will decide. To this extent, therefore, some of the information which would ideally be used in making the decision is inherently unavailable. In practice, of course, there will be uncertainty about the values of some quantities which are in principle measurable. Thus the exact effects, in numerical terms, of a decision cannot

generally be determined. The models used should make some provision for dealing with risk and uncertainty in their parameters. (The distinction between risk and uncertainty is that risk occurs where the possible outcomes and their relative probabilities are not known and cannot be determined, or there may be some unknown possibilities). In some cases the uncertainty is included from the outset, whereas others can be used to find the effect of uncertainty on an already derived solution (this is termed "sensitivity analysis"), but models which cannot deal with any uncertain data are to be avoided.

Byrd (1975) distinguishes three levels of decision: operational (in which there is a single, well-defined objective), strategic (many objectives, which may conflict, although the general policy is established) and policy (where even general policy is not known). In these terms, the decisions made in solid waste management planning are mostly strategic, although they may involve policy elements. Policy conflicts may well arise between the various groups of decision-makers involved, but within a group (e.g. the local authority making the plan) there should be enough consensus on policy to concentrate on strategic issues. In fact, the Department of the Environment (1977) has advised that "the overall objective of a waste disposal strategy is the disposal of waste at the least possible cost to the community with due regard to the safeguarding of the environment and the use of waste as a resource". This is a statement of policy, rather than strategic objectives (it leaves questions like "what is the 'cost to the community'?" and "how much regard is due to the environment?" to be decided). This advice will probably be widely followed, though an alternative

policy (say, disposal with the least possible damage to the environment with due regard to the cost to the community) might be worth considering, perhaps in a time of less financial stringency for local government.

The way that the advice just quoted was framed makes it clear that an optimising approach is expected. Simon (1957) argues that people, and organisms in general, do not normally seek to optimise any specified objective, but rather to achieve acceptable values for all the objectives - he refers to this as "satisficing". Where the situation is uncertain, as it always is in practice, straightforward optimisation may be unsafe, since the best solution will usually be limited by some practical constraint (otherwise it could have been improved on), and if this limit is uncertain, it may turn out that the proposed solution is not feasible. Some workers have attempted to interpret this "satisficing" idea in models for decision-making under risk. For instance, Charnes and Cooper (1963) propose maximising the probability that the required conditions will hold, thus formally making the satisficing problem into an optimising one, which has a unique solution and is entirely deterministic. This is an interesting approach, but unfortunately it seems not to have received much attention for practical problems, perhaps because of excessive computational requirements in solving the deterministic problem produced.

The various forms of uncertainty discussed above are easily classified along the lines suggested by Friend and Jessop (1969) and discussed in section 2.3. The relation to other decision-makers can be identified with uncertainty

about related fields of choice, uncertainty about the effects of decisions with uncertainty about the environment, and the strategic (as distinct from operational) decision with uncertainty about the value judgements to be made. The main problem in strategic planning is to reduce these uncertainties and clarify the objective, leaving the actual implementation for operational decision-makers. This is why, as has previously been remarked, the main value of an operational research investigation may lie not so much in the solutions produced as in the clarification of thinking required in the process. In describing the various models in the following chapters, therefore, the discussion will include the thinking that leads to them as well as the results they provide.

3.3 Using Computers in Operational Research

The increasing use of operational research since the discipline began in the 1940's, and the tendency towards larger and more complex models, can largely be attributed to the availability of increasingly powerful computers to more and more organisations. The availability of methods to solve problems posed in particular forms has had a major effect on the way in which OR problems are formulated - this is particularly noticeable in the case of linear programming (see section 3.5), whose pre-eminence is largely due to the historical availability of solution techniques, and its inherent greater speed of solution compared to related problems. Although details of the computational methods used will not be considered here, the practicalities of using a particular model are sufficiently important to have influenced the development of the research. Some background

information on the use of computers is therefore needed.

Figure 3.1 shows the general organisation of a large computer, such as the main University computer used for most of the work described here. The central processor unit (CPU) is the heart of the machine. It carries out a limited range of operations (typically about a hundred different operations may be available); these would include basic arithmetic such as adding two numbers, transferring information between other units of the machine and altering the area of store from which it takes its instructions. The main store contains not only the instructions for the CPU, but also the numbers or other data on which it operates. It is divided into units called "words", each of which would typically hold one instruction or number. This main store is sometimes called the "core store", because it is often constructed using magnetic cores as the storage elements (though in recent computers these are less often used).

The capacity of the main store is limited, because of its cost, so it is useful to have other, cheaper forms of "backing store", such as magnetic drums, discs and tapes. Information can be stored in these forms and recovered later as it is needed. It is also necessary to have some means of feeding data into the machine and obtaining the results from it; the devices used for these purposes, and for backing storage, are collectively known as "peripherals". Input peripherals at Aston include punched card and paper tape readers, while the output peripherals include a line printer (so called because it achieves high operating speeds by printing a complete line of output at once) and a digital plotter for producing graphs, maps, etc.

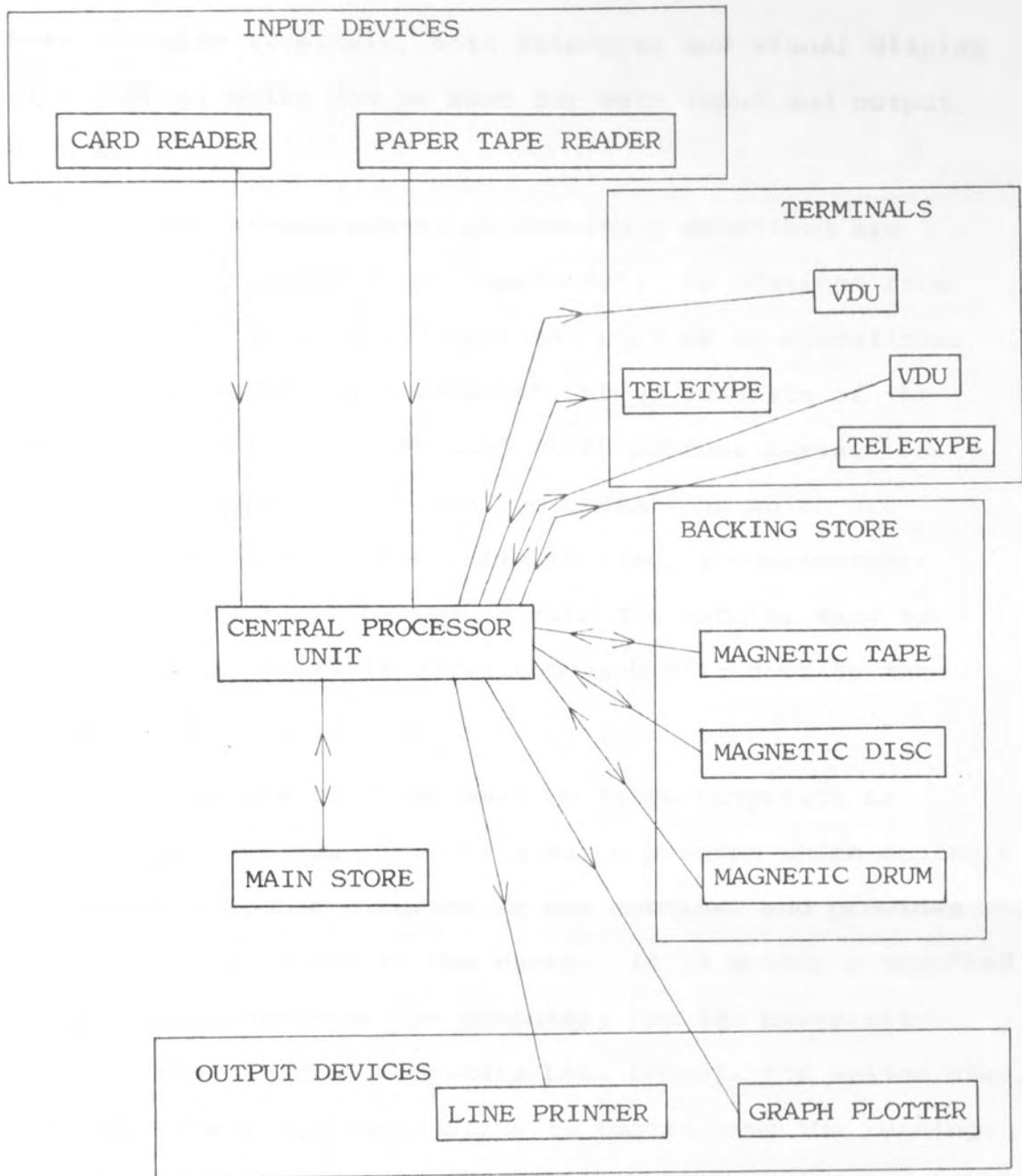


FIGURE 3.1 GENERAL ORGANISATION OF A LARGE COMPUTER

There are also terminals, both teletypes and visual display units (VDUs), which can be used for both input and output of data.

All the various pieces of machinery described are collectively referred to as "hardware". As distinct from them, there is an equally important part of an operational computer system called "software", which consists of the sets of instructions (programs) which produce certain basic (to the user) actions. Since the operations which are basic (to the machine) are quite limited, a considerable amount of software is needed to make the machine easy to use, and the software is often comparable in cost to the hardware.

One vital piece of software on large computers is the operating system. This is a large program which controls the running of other programs in the machine, and provides various basic services to the users. It is normally supplied by the manufacturers of the computer; on the University machine (International Computers Ltd. 1904S), the system used is called GEORGE 3. In addition to controlling the running of programs, GEORGE provides facilities for storing information on backing store devices as "files", which can be referred to by name - the user does not need to know the physical form of storage used. Programs can read in data from files, and send output to them; files can also be used to store the programs themselves, and sequences of instructions to GEORGE (known as "macros") which carry out operations needed repeatedly. GEORGE provides facilities for "editing" the contents of a file, listing all or part of them on the line printer, creating new files from card or paper tape input, etc. With these facilities, it is usually more convenient to store

information in files than to use external media such as punched cards. Another facility is called MOP (for Multiple On-line Programming). This allows a number of users to carry out jobs at the same time, using teletype or visual display unit (VDU) terminals. Programs can be run taking their input from the terminal and sending their output to it; this makes it possible to use the program interactively, i.e. the program can print a question and read the user's reply. Each user can have the impression that the machine is available to him alone, since GEORGE switches from one job to another too rapidly for the interruptions to be noticed.

As noted above, there is only a small range of basic operations, and those available differ from one type of machine to another. When writing a program it is helpful to be able to express it in terms not too far from those normally used for the problem in question, and in a way which can be used on different machines. These points are met by the use of "programming languages", of which probably the most widely used in technical work is FORTRAN. These special languages provide a way of expressing a wide range of problems in a form which is relatively readable to humans (compared to the basic machine instructions for the same problem), and which is independent of the particular type of computer being used. A special program called a compiler translates a program in one of these languages into the internal machine code; the compilers for major languages like FORTRAN are usually supplied by the computer manufacturers. The programs described in this thesis were all written in FORTRAN (for an introduction to this language,

see McCracken (1965)). (Note the use of the spelling "program" when referring to a computer program, as distinct from "programme" in other senses - this is usual in this country, and will be used here).

For some specialised applications, including some areas of operational research, yet another level of software is often provided by the manufacturer or others. This is the "package", a program designed to solve a common type of problem. The data are fed in according to the instructions, and the output is given in some standard format. Some more sophisticated packages provide limited control over the formats of input and output. In the case of OR, the most important package commonly provided is that for linear programming. Since this application requires substantial amounts of calculation, it is valuable to have a standard program which is carefully designed to operate efficiently. Sometimes other OR packages, for purposes such as simulation, are available, but these have not been used in the present work. Another common package which has been used, however, is the statistical analysis package. There are many different packages in existence, some designed for specific types of problem and available on many different types of computer, while others are provided by computer manufacturers specifically for their own machines. These packages provide facilities for various standard types of statistical analysis of data, and often some limited forms of manipulation of the data (perhaps taking the logarithm of the figures, or averaging monthly readings to give an annual figure).

3.4 Regression Analysis

Regression analysis is a technique used to relate some quantity of interest to one or more others. In its basic form, it assumes that a relationship exists having the form

$$y = a_0 + a_1x \quad \dots (3.1)$$

where y , the quantity of interest is related to x , and a_0 , a_1 are constants. By considering a number of pairs of values (x_i, y_i) , and assuming that

$$y_i = a_0 + a_1x_i + \epsilon_i \quad \text{for all } i,$$

it is possible to estimate the values of a_0 and a_1 ; these are chosen in such a way that the sum of the squares of the errors, $\sum_i \epsilon_i^2$, is as small as possible. This choice has convenient mathematical properties and can be regarded as the "best" choice of the constants in a certain sense. It is also possible to estimate the likelihood that a relationship of the form (3.1) does in fact exist (rather than appearing in the data purely by chance). This is expressed in terms of "confidence levels"; for instance, a confidence level of 5% means that there is one chance in twenty that the apparent relationship is due simply to the particular choice of the (x_i, y_i) .

The resulting regression equation, expressing y in terms of x , can be used to estimate the value of y for any given value of x . This tends to suggest that y depends on x in some way, and indeed it is usual to refer to y as the dependent variable (and x as the independent variable). However, no causal connection need exist directly; it is quite possible that both x and y depend on some other variable

which has not been measured, or indeed that x is causally dependent on y but easier to measure.

The equation as given implies that the relationship is linear (i.e. a graph of y against x would be a straight line). The constant a_0 is called the intercept, and a_1 the gradient. It is possible to represent some other forms of dependence, for instance exponential functions, by transforming the data before performing the regression. Other forms, for instance a polynomial, can be dealt with using the more general multiple regression analysis (in which there are several independent variables). As well as giving the relationship quantitatively, for use in estimating the value of y , the simple form is often used to ascertain whether there is any kind of relationship between the two variables. Smillie (1966) gives a straightforward introduction to regression analysis, and Draper and Smith (1966) have a more detailed discussion.

The calculations necessary can be carried out by hand for small quantities of data, but it is usually more convenient to use a computer when several analyses are to be carried out on the same data (many electronic calculators will perform the calculations, but the data must be keyed in each time, whereas a computer can store the data and use them repeatedly). Most manufacturers provide subroutines or complete program packages to carry out the calculations on their computers (e.g. International Computers Ltd. (1971)). Packages providing such facilities on several different types of machine, such as SPSS (Nie, Bent and Hull (1970)) are also widely used, and routines for these calculations have been published (e.g. Cooley and Lohnes (1962)). In the present work, simple regression calculations have been

carried out using specially written FORTRAN programs, for ease of manipulation of the data before performing the actual regression, while multiple regression analysis has used the manufacturer's package. For simple regression, a graph of the data showing the line fitted is a useful addition to the numerical output, and the specially written programs also provide this facility, using the computer's graph plotter. Examples of the use of these programs will be found in chapters 4 and 5.

3.5 Linear Programming

Linear programming (often abbreviated to LP) is a technique for finding a programme of activities subject to linear constraints, which will minimise (or maximise) a linear function. It is important not to confuse the term "programming" here with the job of producing a computer program; this is particularly liable to happen because almost all practical applications of LP involve the use of a computer to perform the calculations. Formally, a general LP problem may be stated as:

$$\begin{aligned} \text{Minimise } C &= \sum_i c_i x_i \\ \text{subject to } \sum_i a_{ij} x_i &\leq b_j \quad \text{for all } j \\ \text{and } x_i &> 0 \quad \text{for all } i \end{aligned}$$

Here x_i is the level at which activity i is undertaken (which according to the second inequality cannot be negative), and the objective function C is to be minimised subject to the set of constraints expressed by the first inequality. For instance, x_i may represent the amount of some commodity produced by method i , c_i the cost of

producing one unit by this method, and a_{ij} the quantity of raw material j used in producing one unit by method i , while b_j is the total stock of raw material j . Thus the problem is to minimise the cost of production while not demanding more raw materials than can be supplied.

In practical problems, much greater complexity of formulation of the problem may disguise the fact that the basic structure is that of an LP problem. For instance, there are usually a number of different types of constraint, some of which may involve $=$ or \geq rather than \leq limitations, but formally these can all be reduced to the standard form. (In practice most computer packages for LP will accept all these forms of constraint). In the simple example given, there is no apparent reason to undertake any activities at all ($x_i=0$ for all i is the optimal solution) unless another constraint is imposed that the production must be at least d , i.e.

$$\sum_i x_i \geq d$$

If there are n raw materials ($j=1,2,\dots,n$), this can be regarded as constraint $(n+1)$, with $a_{i,(n+1)}=1$ for all i .

There is an efficient technique, known as the simplex method, by which it is possible to solve problems of this form; for a discussion of this procedure, see (e.g.) Gass (1969). For all but the very simplest of cases, the calculations are very tedious, and it is usual to use a computer for any practical application of LP. As with regression, published codes are available (Land and Powell (1973)), and most major manufacturers provide programs for their computers (e.g. International Computers Ltd. (1969)).

With some ingenuity, a very wide range of problems that arise in practical planning may be represented as linear programming problems. Indeed, certain special cases of LP, such as the transportation problem (Hitchcock (1941)) are surprisingly flexible as well as computationally more efficient than general LP. In recent years, however, increasing attention has been paid to even more general problems than those of LP form. Nonlinear, stochastic and mixed integer programming are such extensions of the field known overall as mathematical programming; these are computationally more expensive, and usually depend on extensions of the simplex method for their solution. A useful discussion of the practical use of LP and its extensions is given by Beale (1968). The present work has involved the use of specially written FORTRAN programs for some special cases of LP, as well as manufacturer's programs for general LP and transshipment problems (International Computers Ltd., 1969, 1968). Discussion of the problems dealt with and the use of these programs will be found in chapter 6.

3.6 Flows in Networks

One of the most important special cases in mathematical programming is that dealing with flows in networks. Network flows need not, in fact, be restricted to linear cases, but only such cases will be considered here. Since the concept of network flows will be a central one in chapter 6, it is worth discussing this special case in more detail, and from another point of view than that of linear programming.

A network consists of a set of nodes and a set of arcs

connecting them. Not all the possible arcs need be present; we shall consider the arcs to be directed, that is, the arc from node x to node y is different from that from y to x . A simple example of a network is shown in figure 3.2; this network consists of four nodes x , y , s , t , and six arcs (s,x) , (s,y) , (x,y) , (y,x) , (x,t) and (y,t) . If we consider this network as representing a system of distribution, for instance a road network with facilities at the nodes, then we can imagine flows of some sort proceeding along the arcs. Thus numbers can be attached to each arc characterising it in such ways as the flow along it, the unit cost of using it, the maximum flow it can accept (its capacity) and so on. If s is a factory, x and y are transfer points (without storage) and t is a customer, then the net flow out of s (along all the arcs leading from it) will be positive, that from x and y will be zero and that from t will be negative (i.e. a net flow in to t); thus a number can be attached to each node characterising it as a source or sink for the flow under consideration, or an intermediate node which is neither source nor sink.

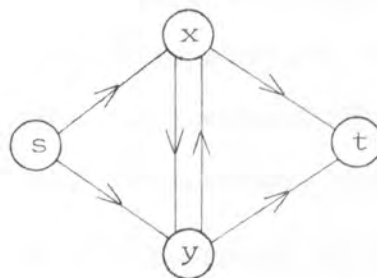


FIGURE 3.2 A SIMPLE NETWORK

(After Ford and Fulkerson (1962))

Suppose that it is required to find the minimum-cost arrangement for transporting material from sources to sinks,

when there is a specified supply available at each source and a specified demand at each sink. If we number the supply points from 1 to n_s , the demand points from (n_s+1) to (n_s+n_d) and the intermediate points from (n_s+n_d+1) to $(n_s+n_d+n_i)$, this can be formulated as:

$$\begin{aligned} & \text{Minimise } \sum_{i,j} x_{ij} a_{ij} \\ & \text{subject to (a) } x_{ij} \leq c_{ij} \quad \text{for all } i, j \\ & \quad \quad \quad \text{(b) } \sum_j x_{ij} \leq s_i \quad \text{for } 1 \leq i \leq n_s \\ & \quad \quad \quad \text{(c) } \sum_i x_{ij} = \sum_k x_{jk} \quad \text{for } (n_s+n_d+1) \leq j \leq (n_s+n_d+n_i) \\ & \quad \quad \quad \text{(d) } \sum_i x_{ij} \geq d_j \quad \text{for } (n_s+1) \leq j \leq (n_s+n_d), \\ & \quad \quad \quad \text{(e) } x_{ij} \geq 0 \quad \text{for all } i, j \end{aligned}$$

where x_{ij} is the flow from node i to node j ,
 a_{ij} is the unit cost of flow from i to j ,
 c_{ij} is the capacity of the arc (i,j) ,
 s_i is the supply at i ,
and d_j is the demand at j .

Constraint (a) states the arc capacity limitation,
(b) the limit on supply at i ,
(c) the conservation requirement at j ,
(d) the requirement that demand be satisfied at j ,
and (e) the requirement that all flows be positive.

If constraint (c) is restated in the form

$$(c') \sum_i x_{ij} - \sum_k x_{jk} = 0,$$

then this is clearly an LP problem (see the preceding section).

The problem just stated is called the transshipment problem (Orden (1956)). It can be reduced to a slightly more

restricted (looking) form called the transportation problem, in which there are no intermediate points, and this can be solved by a form of the simplex method which is quicker and requires less computer storage than the true simplex method for a general LP problem. There are other ways in which this problem may be tackled, however, which may be even more efficient computationally. Ford and Fulkerson (1962), as well as a general discussion on network theory and applications to problems with an LP-like form, give an algorithm (the "out-of-kilter algorithm") which can be used to solve this problem amongst others. This algorithm, which allows lower as well as upper bounds to be placed on the arc flows, is the basis of one of the programs used in chapter 6.

The way in which the problem was formulated above suggests that all possible arcs must be included (it refers to x_{ij} for all i, j). Formally, a mathematical programming model can allow for this by attaching infinite costs to those arcs which are not included in the actual network. In practice, when coding a problem for solution by a program, the columns (activities) corresponding to these arcs can be omitted. In stating problems later, it will be taken for granted that a reference to something like "all i, j " does not imply necessarily that every combination of i and j must be included; rather this should be read in the sense "all (i, j) ", i.e. all the pairs (i, j) which are of interest.

4. MODELLING WASTE ARISING

In this chapter the various sorts of information about waste arisings that are required for planning will be considered, and the ways in which they can be obtained will be discussed. Because direct data are not normally adequate for planning purposes, this will involve the use of models. I prefer to avoid the use of the term "forecasting" in this context, as it is used in a number of different senses in the literature and is liable to cause confusion; however, these models do "forecast" in one sense or another.

In considering waste arisings, the distinction between "domestic" and "industrial" wastes is important. "Domestic" here is meant to include all waste collected by the local authorities, and "industrial" all other wastes. Those wastes which are industrial in this sense are produced by organisations which (in principle) should have some information on the nature and quantity of waste they produce, and how the waste is likely to change in the future. With some industries, sudden change in the waste, due to a change in the process used, may occur, and if the firm involved is a large one, the change may be significant for the waste disposal problem. Such changes are not predictable by outsiders, so a model produced by a local authority is likely to be of little use in predicting waste arisings for more than one or two years ahead. Indeed, it may be that even those involved would not be prepared to predict the nature of their waste in ten years' time; they might prefer to be free to change without much notice in response to changing conditions. This freedom may cause difficulties for the waste disposal authorities, who may want to restrict

changes in the waste produced.

The situation for domestic waste is quite different. Here there are no large single waste producers, and the forces of change are mainly social rather than technical and commercial. Dramatic changes are therefore less likely, though they can occur; and since there are no managers who can be expected to give predictions of their waste production, the local authority must undertake the job. This chapter is therefore mainly concerned with modelling the arisings of domestic waste, and other wastes currently handled by local authorities, rather than industrial wastes dealt with privately.

The models described here are "forecasting" models in the sense that they assume the arisings to be determined independently of the provisions made for their disposal; in other words, there is no feedback from the decisions to be made to the waste producers. This is obviously not true in general - for instance, a drastic curtailment of the collection service would almost certainly lead to a reduction in arisings (and more use of garden fires, compost heaps, etc.) (Hudson and Marks (1977)). It might be expected (or at least hoped) that large industrial concerns would take some account of the disposal facilities available, when deciding on changes which would affect their waste production; but the disposal of domestic waste is a public service, and it would be politically difficult to force the general public to consider the disposal problem by restricting this service. In this respect, therefore, these models are probably more realistic for domestic than industrial wastes.

4.1 Information Requirements for Planning

Information about the quantity and composition of waste arising is sought because it is needed in order to plan the management of the waste. Before considering how this information can be obtained, some more precise definition is needed; "quantity and composition" is too vague a description of what is wanted. In fact, different sorts of information in different degrees of detail are required for the different aspects of planning.

"Quantity" could mean either weight or volume of refuse. The weight is important if treatment plants are being considered, since these are normally rated in terms of the weight of refuse they can accept per hour; it may be significant for planning the transport provisions, though collection vehicles at least are more often limited by the volume than the weight of their loads. The volume the waste will occupy in a landfill is obviously important, but this will be less than the volume of the refuse measured at the time of collection, since in a landfill compaction and decomposition will increase the density of the material. The volume of refuse is in fact rather difficult to measure in such a way as to produce repeatable results, because it is easy to compact; if the various components of refuse are separated, the volume of the components will be significantly greater than that of the original refuse, because the smaller particles occupy the spaces between larger objects such as cans and bottles in the mixed refuse and do not add to the volume. Though the weight is subject to some variation, due to varying moisture content, this is much less important, and the weights of the components do

add up to the original weight of the refuse. In this study, the weight of refuse has therefore been used as the main measure of "quantity of refuse", with some reference to the volume based on measurements of the density as collected, and the final density of waste in landfill sites.

For different purposes there are also differences in the amount of detail required about the distribution of the arisings in time and space. In order to decide the total landfill space requirement for an all-landfill disposal system, it is sufficient to have a figure for the total arisings in the county in a year. If transport is being considered, some degree of detail on the arisings in different parts of the county will be needed, depending on the accuracy required. If treatment plants are involved, some consideration of the variation of arisings from week to week will be required, since only a few days' refuse can be stored at the plants.

For landfill, the composition of the refuse is unimportant, provided that it does not contain anything which would cause pollution or disrupt the biological processes in the fill. Analysis of the refuse where landfill is the only means of disposal is therefore only needed if it helps to indicate trends in the quantity of refuse, by revealing changes in the quantity of a particular component before the overall quantity has been significantly affected. (It is assumed that hazardous or polluting materials are most unlikely to be found). Where incineration is in use or contemplated, the calorific value of the refuse is of interest. Because refuse is so variable, it is probably easier to analyse the refuse into its components and

calculate the calorific value from the proportions of each than to determine the calorific value of a large enough sample directly. If separation for reclamation is being considered, an analysis into the various fractions to be separated is obviously needed, though when the plant exists this will be available without extra effort.

For general long-term planning of waste management, various possible methods of disposal should be considered, so information will be required on both the quantity of waste arising, in sufficient detail to allow proper consideration of transport costs and the limitations of treatment plants, and its composition, in terms of the detailed components (which will allow the calorific value to be calculated if needed). Information in such detail is rarely available, and in any case it is required to refer to times in the future, for which direct data cannot be obtained; thus the use of models is essential. Before dealing with the models used, however, the sources of data which are available will be discussed.

4.2 Available Information on Waste Arisings

Having put forward rather large requirements for information on waste arisings, we must now consider what is actually available. It is undesirable to demand special data collection unless absolutely necessary, since this will involve new effort and expenditure without any obvious return; also, when considering changes with time, a fairly long time series of data is required, so a newly-initiated data collection will not produce results for several years at least. These arguments were used at the start of this

research to justify the use of existing data rather than new collection, but the West Midlands is probably better supplied with existing information from the old local authorities (particularly Birmingham and Coventry) than most other counties, and in those areas where refuse analyses, and even weighing the collected refuse, have not been carried out previously, it is desirable to begin these forms of data collection as soon as possible to build up information for the future.

It is, unfortunately, the case that many local authorities have very little information on the waste they deal with. At the time of the Sumner report (Sumner et al., (1971)), only 16% of household refuse was weighed (para. 91); the quantity handled is commonly estimated on the basis of the number of vehicle loads, but the variation in the weight of refuse carried by vehicles is such that this is a very inaccurate procedure, which is known to give overestimates in most cases. When landfill is the only means of disposal, accurate figures are not really needed - the site can be surveyed from time to time, giving a direct indication of the rate of use of landfill space (Roberts (1972)), rather than determining the weight of refuse arising and calculating the space needed from that. However, serious long-term planning should consider other possible methods of disposal, unless there is clearly enough landfill space readily available for the foreseeable future (even then there is the possibility that landfill may become unacceptable as a general means of waste disposal in the future, but it may be considered sufficiently unlikely to ignore).

In areas where the refuse is normally weighed, the results may not be recorded in the most helpful way. In Birmingham, for instance, the input to each works is recorded daily, with some breakdown into household and trade refuse, and refuse diverted from other plants as opposed to that normally dealt with by the plant in question. This gives a good indication of the variation with time of arisings in a particular collection area so long as a plant is operating; but if there is a breakdown and the refuse is diverted to a landfill site, it is not weighed. Also, there is no indication of the arisings from particular collection rounds (which could be recorded separately in principle), so differences in the refuse production of different parts of a collection area cannot be observed. Such measurements would also be useful for determining the loads carried by individual vehicles, for costing purposes (this will be discussed in the following chapter).

Apart from the works records, the other main source of information on the arisings in Birmingham is the record of refuse analyses which have been carried out at intervals since 1961. The information recorded in this form is described in more detail in an earlier report, which describes a study of this data with a view to predicting refuse arisings. The text of this report forms Appendix A. Unfortunately this sort of data is available only for Birmingham in the West Midlands, and a few other authorities in the country; and in fact since the report was written the analysis of refuse in Birmingham has ceased. This is because, being an unusual job carried out at one plant

once a quarter, it was overlooked in the production of a new bonus scheme for employees in the plants, and being a hard and unpleasant job, men are not prepared to carry it out without some inducement.

The form of data collected for the analyses has an important limiting effect on the models which can be used, mainly because of the choice of a few small sample groups of dwellings. This gives no indication of the commercial component of collected waste, or of any variation between households except the house/flat and the artisan/middle-class residential distinctions, so that these are the only differences between households that can be considered. It would be very useful to have some information on the differences (if any) between areas of similar types of housing in different parts of the city; nevertheless the data that are available are very valuable, being the only source of information on differences between different dwellings, and it is regrettable that the analyses are no longer being performed.

4.3 Types of Model

This section will outline some of the models available for bridging the gap between the available data and the information required. The important points to note are the assumptions made in each model and the forms of error to which they are susceptible, as well as the sort of information they provide.

The choice of model is essentially a subjective decision, and may have some policy implications; for instance, the choice of "forecasting" models, in the sense commented

on in section 4.1, implies a decision that the demand for disposal will be met (though perhaps this would be reconsidered if the predicted demand was much higher than expected). The nearest approach to an objective choice of model would be to use some criterion like "choose the model which gives the most accurate results over the last few years"; but this may give different results for different choices of the "few years", and also favours models with many adjustable parameters which can be chosen to fit past observations to any desired degree of accuracy.

The most important distinction to be drawn between different types of model is that between those which include some consideration of changes with time and those which do not. When using the latter, either it is assumed that no significant changes will take place during the period of interest, or the changes are considered later as a separate problem. When considering a period of ten years or so for strategic planning, some discussion of possible changes would seem to be essential. Some work in the literature which is described as "forecasting" does not discuss changes with time, but is concerned with the estimation of waste production from particular sites on the basis of that from others whose production is known; examples of this are Graf and Whittenberger (1975) and Harris, Mann and Humphrey (1976). This is referred to by Berry (1977) as cross-section forecasting. Some element of this sort of model is needed if the available data do not come from all the sources to be considered; if refuse analysis records are to be used, for instance, they refer to only a few sample groups of dwellings and

some model is needed to extend the figures to cover the whole area of interest.

The question of extending figures from a small sample to a larger area is one which was not discussed thoroughly in the earlier report (Appendix A), though this was based on refuse analysis data. The assumption made was that the quantity per dwelling would be constant for dwellings in a given range of rateable values. While it was pointed out that variations between groups of dwellings due to other factors than rateable value might exist, there was no discussion of the more basic assumption that the quantity per dwelling was the appropriate measure (rather than, say, quantity per person) - when quantities per person are considered, the method of aggregating to find the "overall" quantity is not re-examined, though it was based on quantities per dwelling. Thus it is not clear whether the basic waste generating unit is the person or the household. In principle it would seem that although the waste output of a household will increase as the number of persons increases, this increase will not be as strong as direct proportion - because, for instance, a large household will use larger packages, which contain less packaging material (waste) in proportion to their contents than smaller ones. This effect does not seem to have been studied; most work simply takes quantity per person or per household without discussion, depending on the form used in the data source. Grossman, Hudson and Marks (1974) mention the importance of the size of households, but do not use it in their correlations because they consider the production of waste by blocks of housing, and they choose to deal with the number of dwellings and not the number of people in a block (they cannot use both because

of the high correlation between them, which would interfere with the calculation of correlation for other variables). An investigation of this topic would seem to be a useful project.

If the variation with time is to be dealt with, the simplest approach is to look at a time series of the quantity of interest, and fit some simple curve to it, perhaps a straight line, a polynomial (as in the previous report) or an exponential. This is, in a sense, a non-model; there is no consideration of the underlying mechanisms producing the change, it is simply assumed that they will cause the variation with time to take some particular form. Since there is at present no detailed understanding of the generation of household waste (social and economic effects are often referred to but never quantified), there would seem to be some justification for avoiding assumptions about it, though it would obviously be preferable to establish such an understanding. This would, however, be a major undertaking, and might well require extensive data collection; the proposal for such an analysis for the Battelle study in Germany (Schneider et al., (1974)) was dropped because the data were not available, and a simple constant output per head was assumed instead.

Alternatively, some plausible assumptions can be made to relate the production of refuse to other factors, whose future values can be predicted more readily. For instance, Green (1969) assumes that the amount of each of the components of refuse (from a standard refuse analysis) will increase at the same rate as the consumption of the relevant material; this will be correct so long as the

increase reflects greater quantities of material being used for the same purposes, rather than any innovation in material use. The consumption predictions are obtained from national statistics (the model used for this is not discussed). Nice (1969) forecasts the production of scrap vehicles from predicted vehicle population and lifetime. A more complex model is used by Stern (1973) to predict changes in industrial waste production, using input-output techniques to allow for the effects of changes in production on the demand for one industry's goods from another; but it is assumed that the output of waste per unit of production will not change, and the increase in consumption of the various products (which is the ultimate cause of all the change in this model) is assumed without explanation (though it could probably be taken from official predictions for economic planning, if these are accepted). In practice this approach seems to be used to relate the refuse production to other factors which are already predicted by others, thus relieving the waste manager of the main responsibility.

There are a number of instances in the literature where, having discussed the data on waste arisings in the past, the authors produce a prediction of future arisings without any detailed explanation, apparently subjectively (e.g. Sumner et al. (1971)). This loses the potential advantages of using an explicit model (discussed in section 3.1). On the other hand, some aspects of the future can only be dealt with subjectively, particularly in connection with the likelihood of sudden major changes, so a careful subjective consideration of the results from a model is highly desirable.

Berry (1977) distinguishes between time series forecasting and exploratory calculation, the former being a calculation of the most likely arisings at some future time, and the latter a calculation of the arisings under some specified conditions which are not considered to be the most likely ones. The "most likely" figure is the one most often sought, but it is questionable whether this is appropriate when the range of uncertainty is large; at least the uncertainty should be indicated, which is rarely done. The engineering practice of "worst case" design is preferable, but in the waste disposal area there is such a large uncertainty that the worst case conceivable may require excessive expenditure for proper handling. In practice, disposal systems seem to cope with intermittent overloads (after holiday periods, for instance) without much trouble, though the cost of such periods is not assessed and may be quite large. Clearly, a policy decision is needed on the frequency of overloading which will be accepted; similarly for the longer-term planning, a decision is needed on the acceptable probability that the whole system will be overloaded in the future, due to the uncertainty in the forecasts. To help with this decision, some indication of the variation of cost with arisings for any proposed system would be desirable. It is likely that the design having the lowest expected cost (if this is the appropriate criterion) will be one whose nominal capacity is rather greater than the expected quantity of waste. This would not be the case if the variation of cost with throughput were linear, but for throughputs above the nominal capacity the unit costs of most systems, with the possible exception of pure landfill, increase rapidly. This point will be

further discussed in the next chapter.

4.4 A Reassessment of the Waste Arisings in the West Midlands

Since we are interested in planning refuse management for a period of about ten years ahead, we must also attempt to predict the waste arisings for at least this long, and preferable longer (in order to compare the value of long-term investments such as treatment plants with alternative shorter-lived arrangements). The best data available for the West Midlands, namely the Birmingham refuse analysis records, date back only to 1961, and are irregular until 1966; thus the time-span covered by the data is similar to that required for the forecast. In this situation it is clearly unwise to attempt to extract too much information from the data - only the broadest general features can be expected to continue for the duration of the planning period. The large scatter of the points, and consequent low correlation coefficients obtained in the previous work, suggest that the trends are not sufficiently well-defined to be examined in such detail as was then attempted (by fitting a cubic polynomial). In re-examining the data, only linear and exponential trends were considered. More sophisticated methods of extrapolating time series (Kendall (1976)) are intended for short-term prediction only.

The refuse analysis data (discussed in detail in section A.2) is based on four small sample groups of dwellings. One way to reduce the scatter of the observations would be to average it out between the four groups. This assumes that the long-term variations are due to some factor(s) which affect all the groups, whereas the scatter about the trend

is due to random effects which are not correlated for the different groups. To test this assumption, linear correlations were computed between the observations of the same component of refuse for different sample groups of dwellings. Significant positive correlations were found in most cases, showing that a significant proportion of the variation is indeed due to factors common to all the groups. The poorest correlations were those involving the high-rise flats, suggesting that there are important differences in waste production between houses and flats.

Both linear and exponential trends were fitted to the data for each sample group, and for the "Birmingham overall" figures, obtained as described in Appendix A. These were of the forms

$$y_i = m x_i + c + \epsilon_i$$

and

$$\ln y_i = \ln a + b x_i + \epsilon_i$$

$$(i.e. y_i = a \exp(\epsilon_i) \exp(bx_i))$$

respectively (note the different assumptions about the form of the error term ϵ_i). The data relating to percentages of various components of refuse were also converted to actual weights of the different materials, and trends fitted to these figures, to determine whether there were clear trends in the quantity of particular materials discarded.

Comparing the results of these fits, on the basis of the correlation coefficients, it appears that in general the exponential trend gives a slightly better fit to the data. Linear fits were slightly better for the density of refuse, and some weights, and substantially better for the

glass content of waste from residential houses. Linear trends in the weight of vegetable and putrescible matter were found for artisan and residential houses, where there was no significant trend in the percentage of this component, and exponential trends in the weight of glass from artisan and middle-class houses were also found where there was no significant percentage trend. No significant trend was found in the weight of refuse from the flats, the paper content of the overall Birmingham refuse, the metals content of waste from middle-class houses or the glass content overall. Because of the important change in the definition of the "unclassified" component, noted in Appendix A, regressions were not considered for this component - instead it was assumed that the mean level since the change would be continued. The predictions made on this basis are shown in Table 4.1 and Figures 4.1 to 4.7.

In the case of the paper component, and to a lesser extent the density, there appeared to have been a change in the trend; this could not be represented by the methods used, so both these variables showed no significant trend. In an attempt to deal with this, two separate linear trends were fitted, one to the early part of the data and another to the remainder. The point at which the data were divided was chosen in such a way that the total residual variance of the observations from the appropriate line was a minimum. There was no constraint that the lines should meet at this point. The results from this approach are shown in Figures 4.8 and 4.9. It will be seen that the trends found for the density do in fact meet at the changeover point (to a good approximation), whereas in the case of the paper content there is a sudden jump in the trend line (as in the

data) at this point.

In some cases, the trend lines do not seem to be realistic as forecasts. The most conspicuous instances are those where the line reaches zero within the forecasting period - the vegetable and putrescible component, and the paper content according to the second calculation (Figure 4.9). Subjectively, it seems most unlikely that either of these components will actually fall to zero in the foreseeable future. For the vegetable and putrescible content, a better prediction ("better" in the sense that it is less implausible) is given by the exponential fit shown in Figure 4.10. The case of the paper content is more difficult, because bearing in mind the previous drastic change, one cannot rule out the possibility of another change in trend; thus it is quite plausible either that the paper content will remain at its recent level (around 30%), or begin to increase as in the past towards 50-60%. This is perhaps the most important question which might be answered by conducting new refuse analyses in Birmingham in the near future.

Table 4.2 shows a projected analysis for Birmingham refuse in 1977, 1982 and 1987, on the assumption that the paper content will remain at about 30%. The other figures in the table are taken from the appropriate projection of those previously shown. Since not all the components were considered (those omitted being the fine screenings and textiles), there is no check for consistency in these results, but the quantity which must be assumed for the omitted components for the analysis to total 100% is quite plausible.

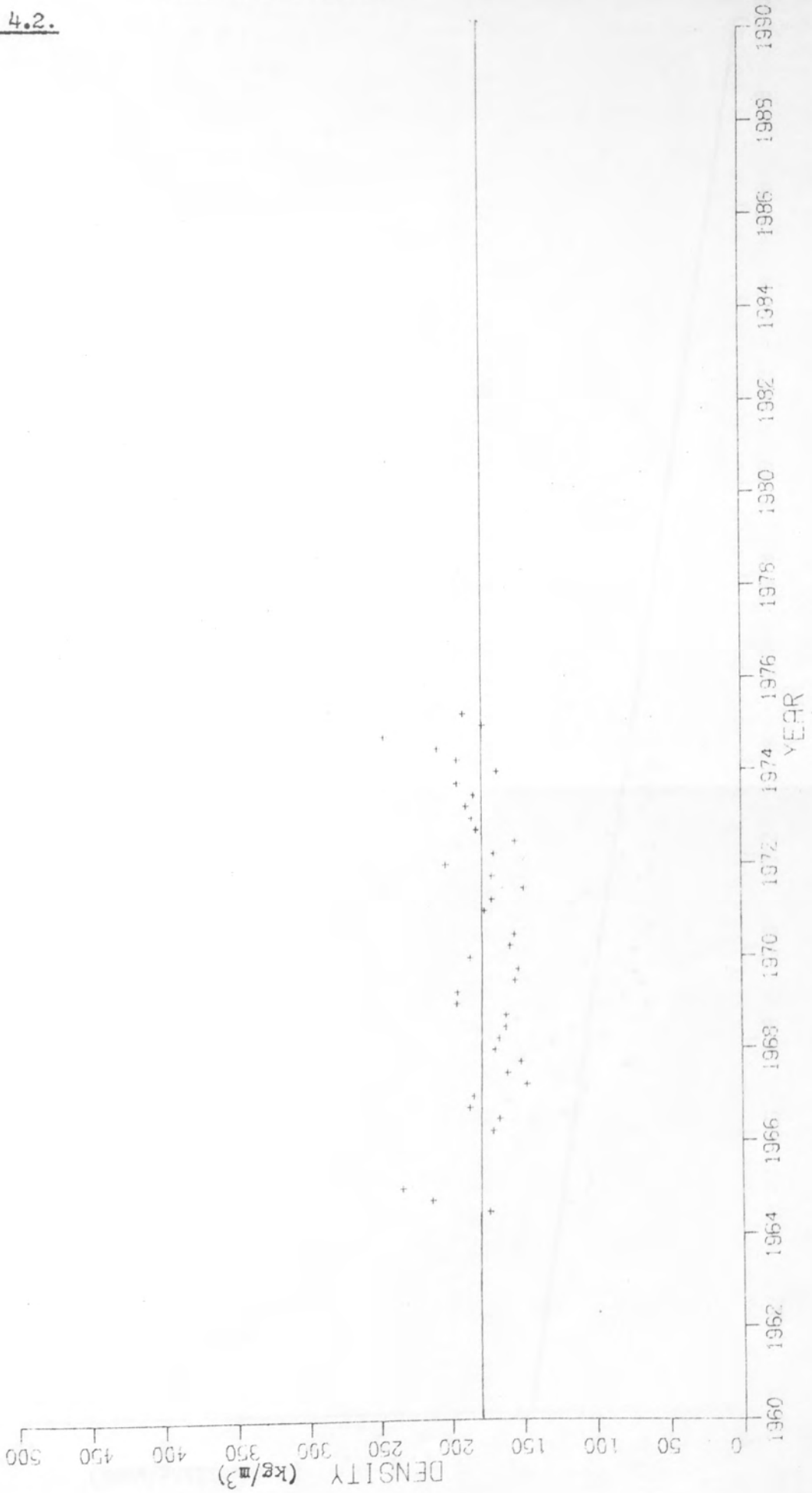
FIGURE 4.1.

BIRMINGHAM OVERALL - WEIGHT



FIGURE 4.2.

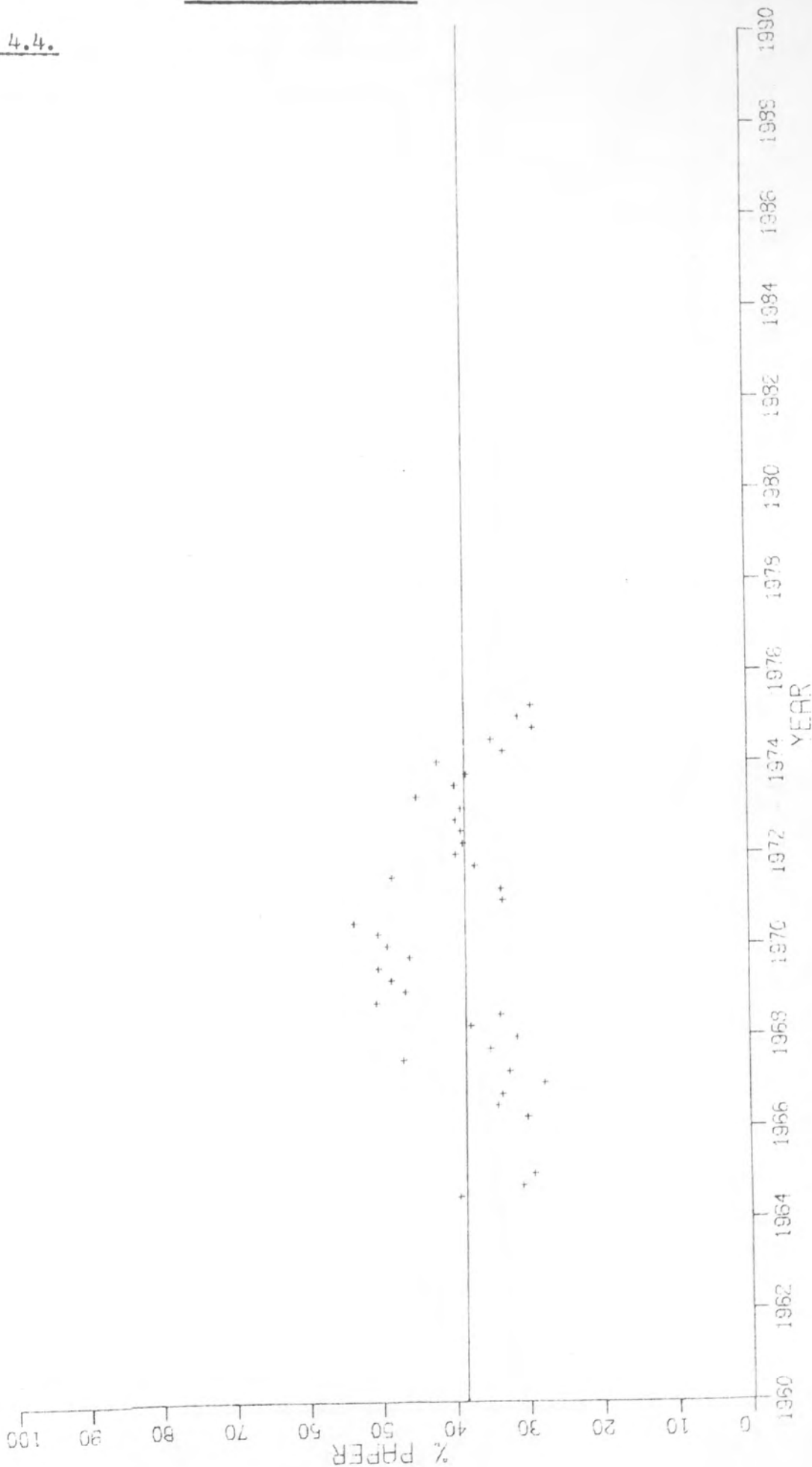
BIRMINGHAM OVERALL - DENSITY



REFUSE ARISING

FIGURE 4.4.

BIRMINGHAM OVERHILL - 7. PAPER



REFUSE ARISING

FIGURE 4.5.

BIRMINGHAM OVERALL - % METALS

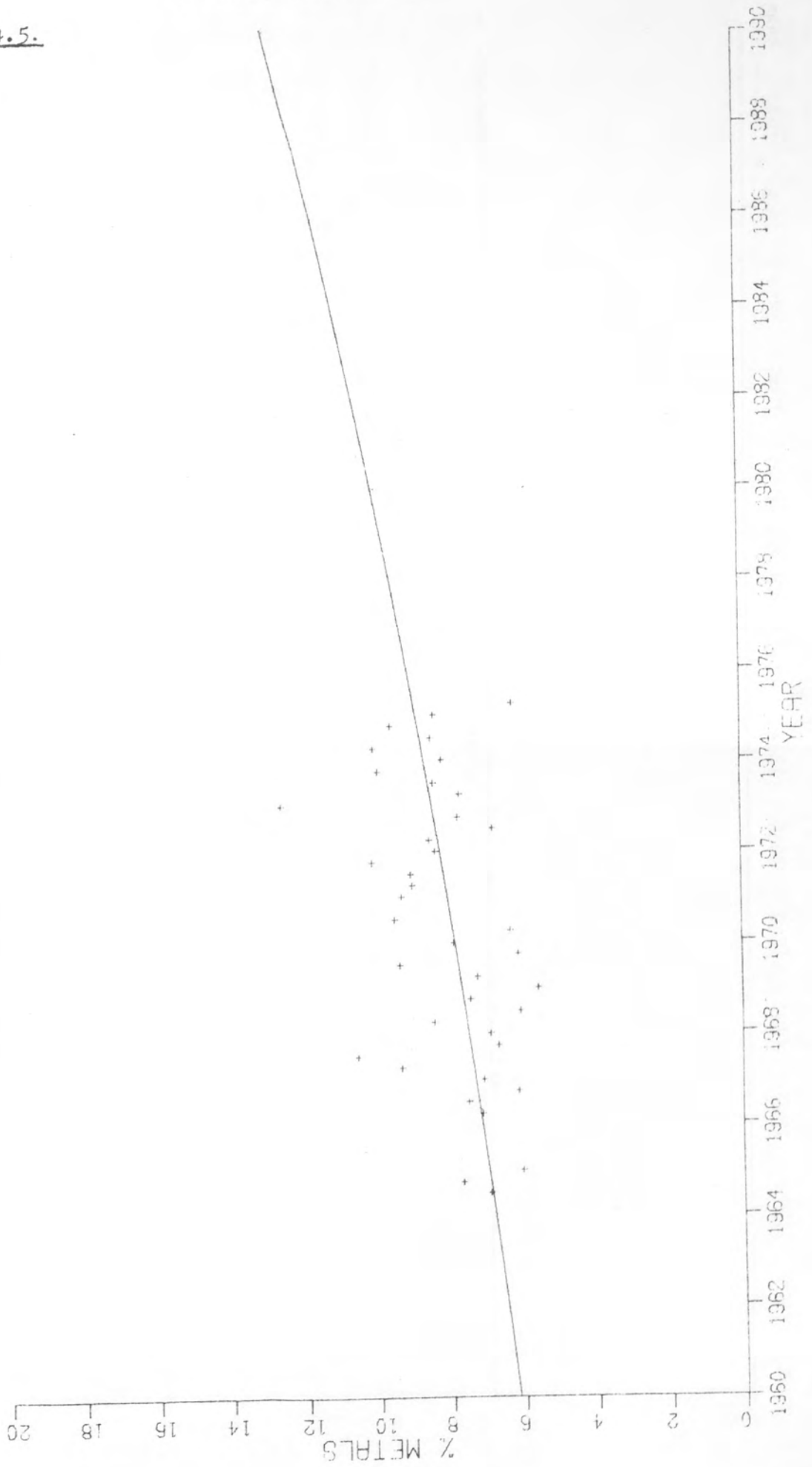
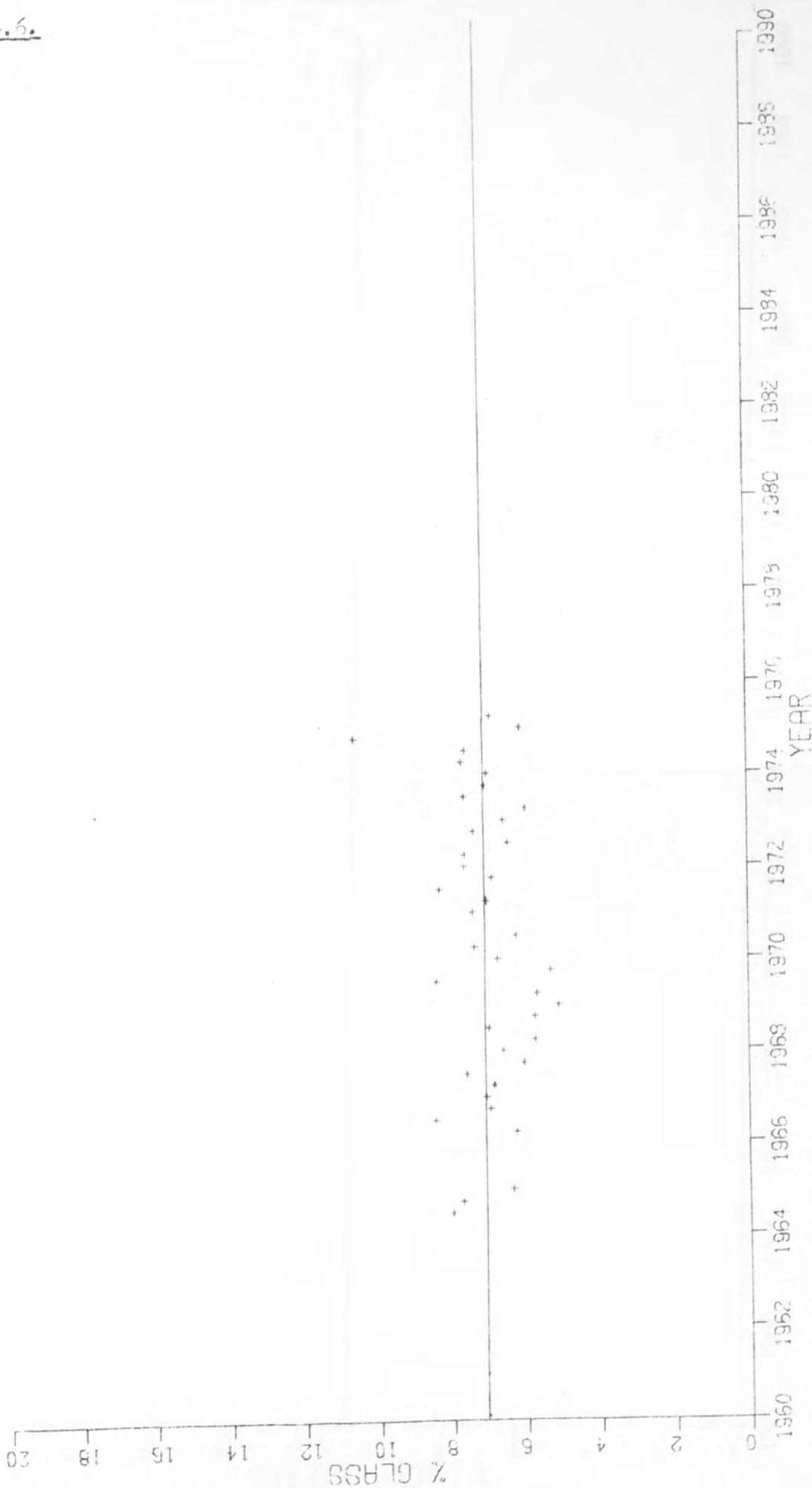


FIGURE 4.6.

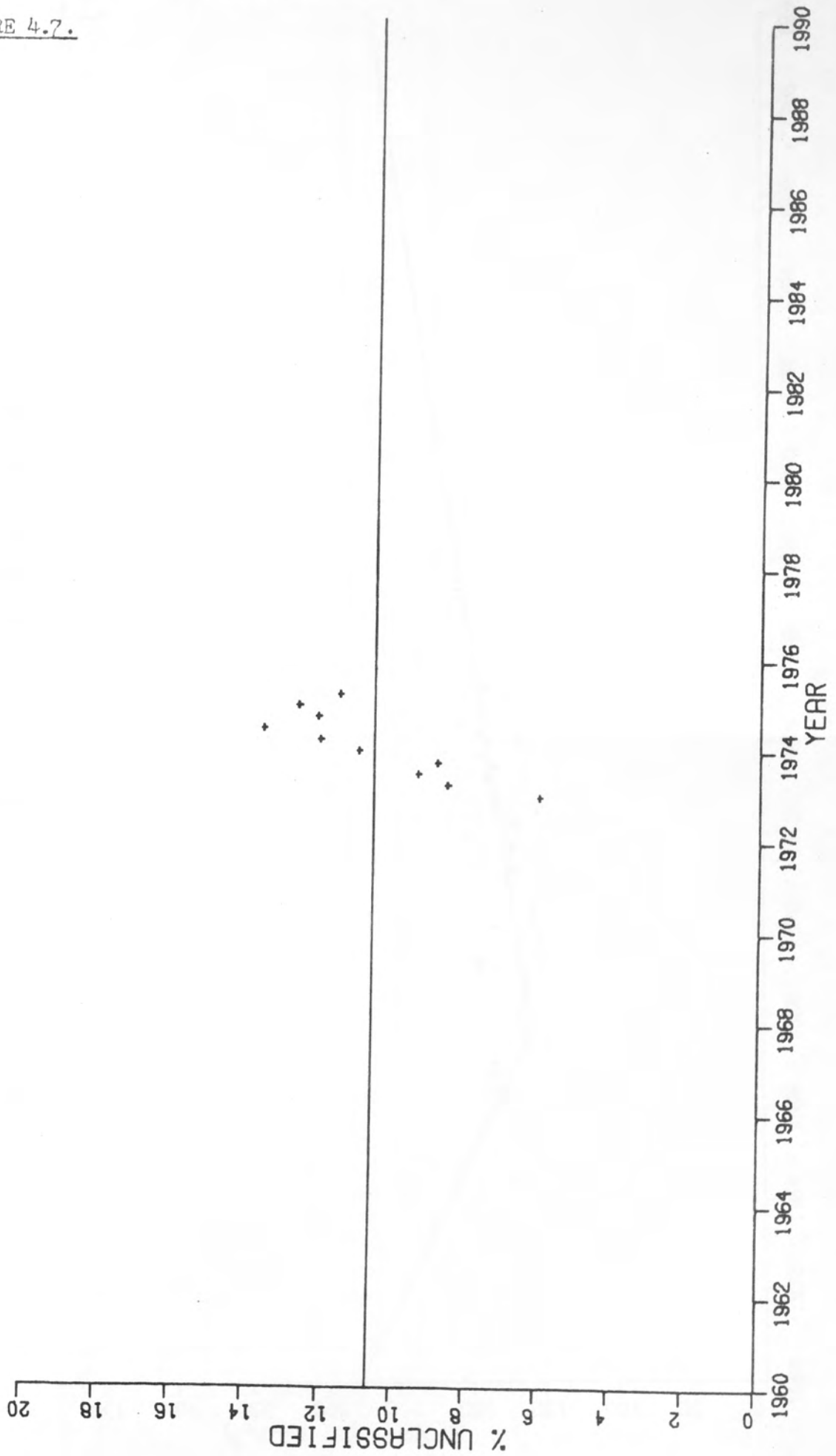
BIRMINGHAM OVERALL - % GLASS



REFUSE ARISING

FIGURE 4.7.

BIRMINGHAM OVERALL - % UNCLASSIFIED



BIRMINGHAM OVERALL - DENSITY

REFUSE ARISING

FIGURE 4.8.

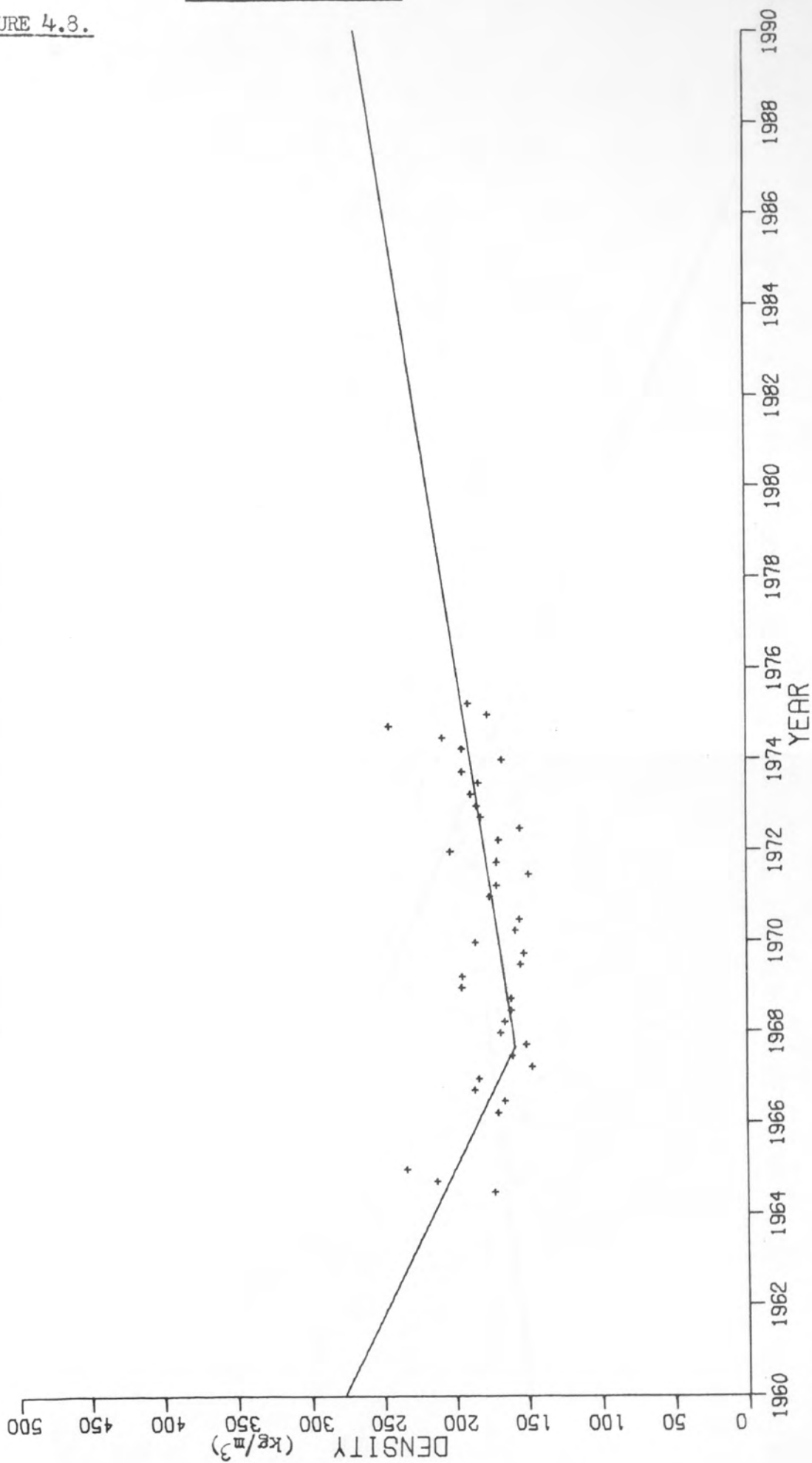
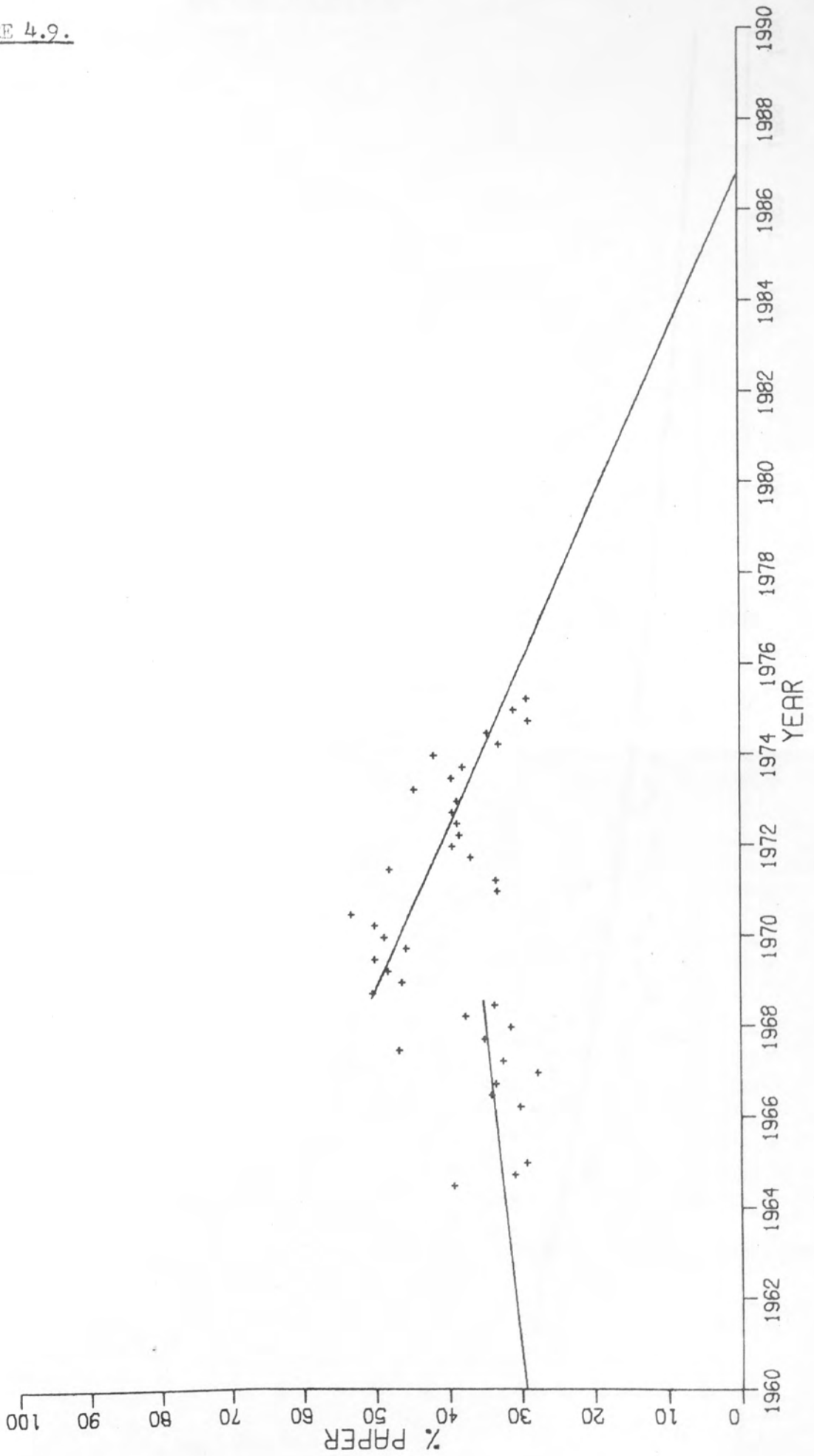


FIGURE 4.9.

BIRMINGHAM OVERALL - % PAPER



REFUSE ARISING

FIGURE 4.10.

BIRMINGHAM OVERALL - V. & P.

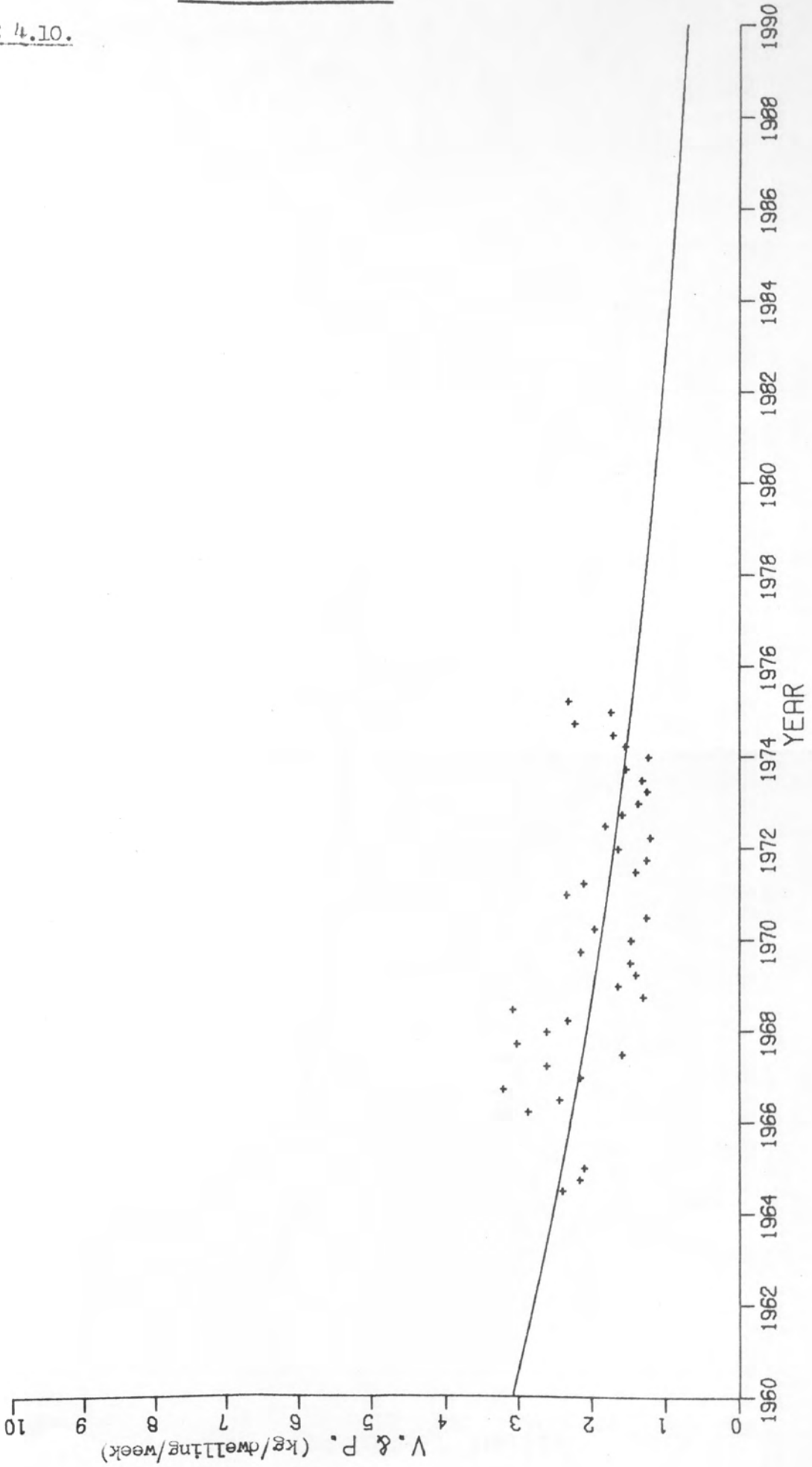


FIGURE 4.11.

TOTAL REFUSE COLLECTED IN BIRMINGHAM

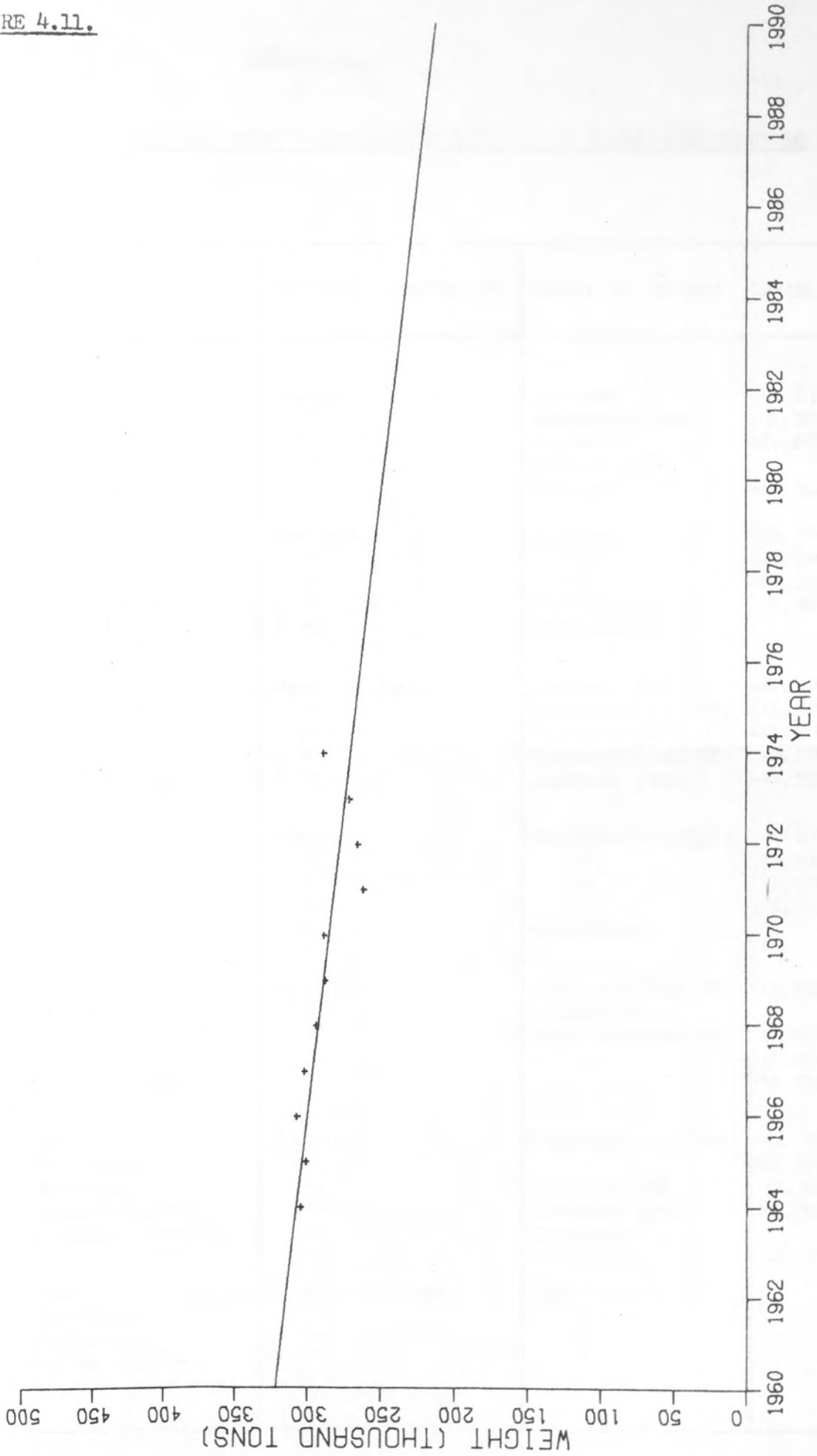


TABLE 4.1

TRENDS IN THE QUANTITY AND COMPOSITION OF DOMESTIC REFUSE

TYPE OF HOUSING	REFUSE COMPONENT	FORM OF TREND	CORR. COEFF.
Artisan	Weight	Linear	-0.5186
Middle-class	"	Exponential	-0.3928
Residential	"	Linear	-0.6790
High-rise flats	"	Constant	
Birmingham overall	"	Linear	-0.3263
Artisan	Density	Linear	-0.3848
Middle-class	"	"	-0.5444
Residential	"	"	-0.5272
High-rise flats	"	"	0.4950
Birmingham overall	"	Constant	
Artisan	Veg. & Put.	Linear (wt)	-0.2748
Middle-class	"	Exponential (%)	0.3676
Residential	"	Linear (wt)	-0.2581
High-rise flats	"	Exponential (%)	0.5742
Birmingham overall	"	Linear (wt)	-0.5285
Artisan	Paper	Exponential (%)	0.6156
Middle-class	"	"	0.5160
Residential	"	"	0.3693
High-rise flats	"	"	-0.3609
Birmingham overall	"	Constant	
Artisan	Metals	Exponential (%)	0.6090
Middle-class	"	Constant	
Residential	"	Exponential (%)	0.4739
High-rise flats	"	"	0.4441
Birmingham overall	"	"	0.4075
Artisan	Glass	Exponential (wt)	-0.3192
Middle-class	"	"	-0.3260
Residential	"	Linear (%)	0.3184
High-rise flats	"	Linear (wt)	0.3360
Birmingham overall	"	Constant	
Artisan	Unclassified	Constant	
Middle-class	"	"	
Residential	"	"	
High-rise flats	"	"	
Birmingham overall	"	"	

The uncertainties in the figures quoted are difficult to assess with any degree of accuracy. The scatter in the graphs indicates the size of the variation which can be expected for a single week from a small area, of the order of $\pm 20\%$ for the weight and as much as $\pm 50\%$ for some components. Figure 4.11 shows the annual total collected refuse in Birmingham (C.B.C. area) between 1964 and 1974 (City of Birmingham Salvage Department figures), which show variations of about $\pm 5\%$ even in this highly aggregated form. Thus the uncertainty in the predictions for any one year must be at least of this order. In addition there are errors in the estimates of the trends, and the possibility that the trends may actually change with time. Both these factors cause the predictions to become more inaccurate as they are extended further into the future. The standard error in the trend for the weight, for instance, would lead to an uncertainty of about $\pm 20\%$ in 1987; the effect of sudden changes cannot really be expressed in the same form, but having observed one significant change at least (in the paper content) in the last decade, it must be assumed that there is a substantial probability that a comparable change in another component will occur in the course of the next decade. Thus the figures quoted in Table 4.2 must be regarded as very approximate; at best, perhaps $\pm 20\%$ for the overall weight in a year, and at least $\pm 50\%$ for the composition of any operational sample. Such large uncertainties about the quantity and composition of the material to be dealt with will obviously have an important influence on the choice of a waste disposal system. It is quite unrealistic to consider any approach which relies on a well-defined

TABLE 4.2PROJECTED QUANTITY AND COMPOSITION OF BIRMINGHAM DOMESTIC WASTE

REFUSE COMPONENT	1977	1982	1987
Weight (kg/household/wk)	10.8	10.0	9.2
Density (kg/m ³)	208	233	258
Veg. and Put. (%)	10.6	11.1	11.8
Paper (%)	30	30	30
Metals (%)	9.5	10.7	12.2
Glass (%)	7.1	7.1	7.1
Unclassified (%)	10.6	10.6	10.6

specification of waste.

Finally, it should be pointed out once again that the work in this chapter refers only to household waste. Figure 4.11 shows the total refuse collected, including commercial waste, which in 1973 amounted to about 273 000 tons, whereas the quantity calculated from the arisings per household (11.3 kg/dwelling/week from 331 000 dwellings) is about 191 000 tons. Thus the arisings from trade sources are very significant in the total collected refuse (assuming this to be the main cause of the discrepancy), and they have not been dealt with at all in this work.

4.5 Space and Time Distribution of Arisings

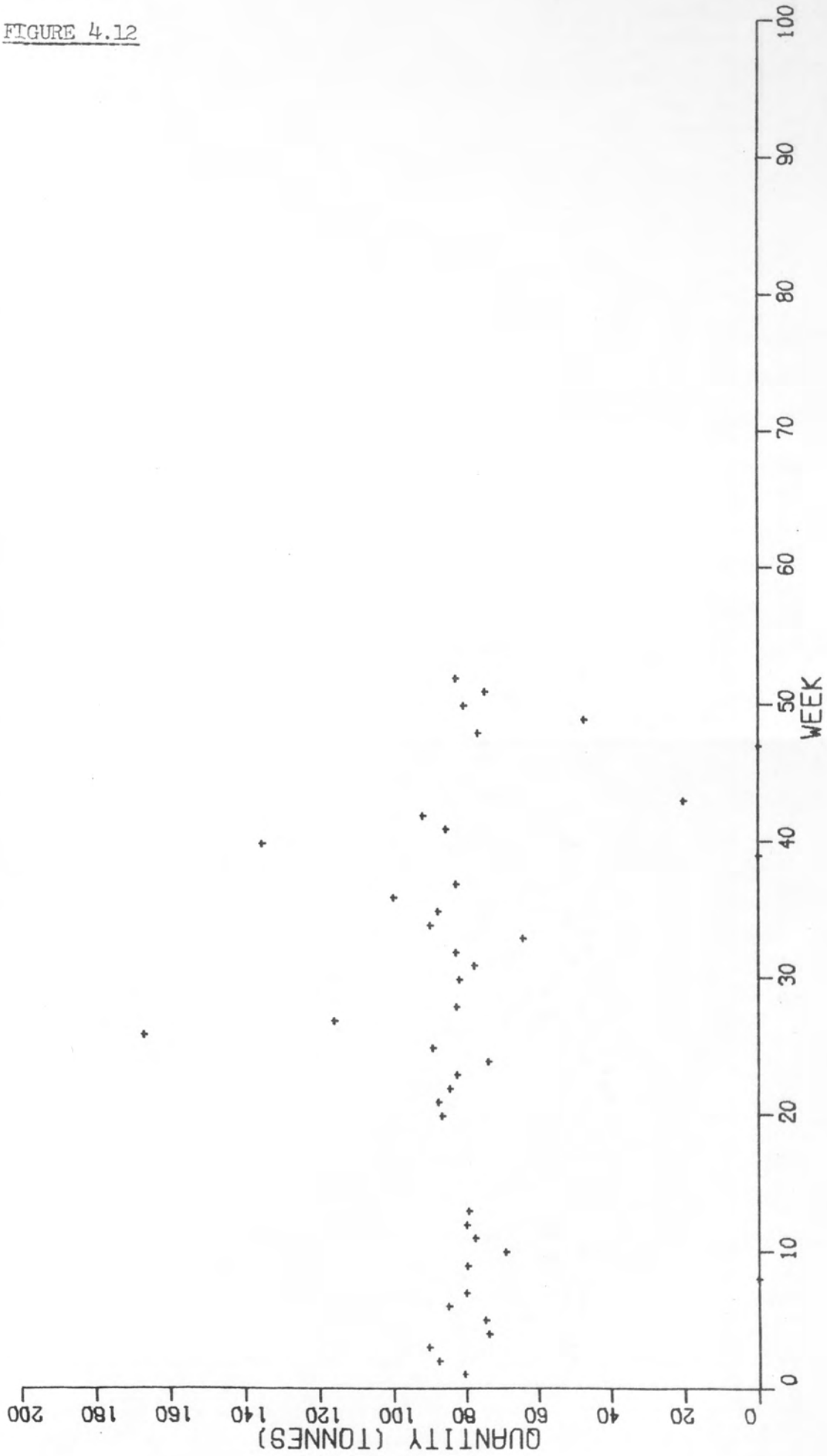
As noted above, some information on the way that the total waste arisings are distributed in time and space is needed when considering the transport of waste and the use of treatment plants. It is difficult to assess the spatial distribution of present arisings, because of the absence of suitable records. The arisings in each district can be estimated; although in some cases, where landfill is the usual means of disposal, the figures are of doubtful accuracy. Unfortunately the refuse analysis information considered above cannot be used to estimate the total quantity of collected refuse, since (as has already been emphasised) it does not include any consideration of commercial wastes. The assumption that the proportion of commercial to household wastes is the same for each district in the West Midlands, which appears plausible, gives results for the total arisings in each district that are very different from those obtained directly, and it is not possible to be certain as to what

proportion of the discrepancy is due to the unreliability of the direct figures, as opposed to real differences in waste generation in the different areas. Spatial distribution has therefore been dealt with in a fairly crude way in the present work; the best available figure for the arisings in each district have been used, and where a district has been divided into several areas for the purpose of calculating transport costs (see chapter 5), the arisings have been divided subjectively, mainly on the basis of estimated population. When calculating the arisings for the future, no account has been taken of changes in the distribution of population - the distribution of arisings has remained the same for all time periods.

The distribution of the arisings in time is significant because of its irregularity, which (as noted above) can cause difficulties with the operation of treatment plants. Most recently constructed plants have substantial storage capacity in their input bunkers, which provide sufficient stock for 24 hours or more of normal operation. These plants are therefore unaffected by fluctuation in input on the time-scale of a few hours, such as are caused by the schedule of collection activity; they may also have the capacity to hold some stock for several days, to reduce the effect of variation in the amount collected from day to day within a given week. However, the storage system used, tipping into a bunker which is emptied by a grab crane, means that the most recently delivered material is dealt with first, while that held in stock remains at the bottom of the bunker. If stock is held for more than a few days, it

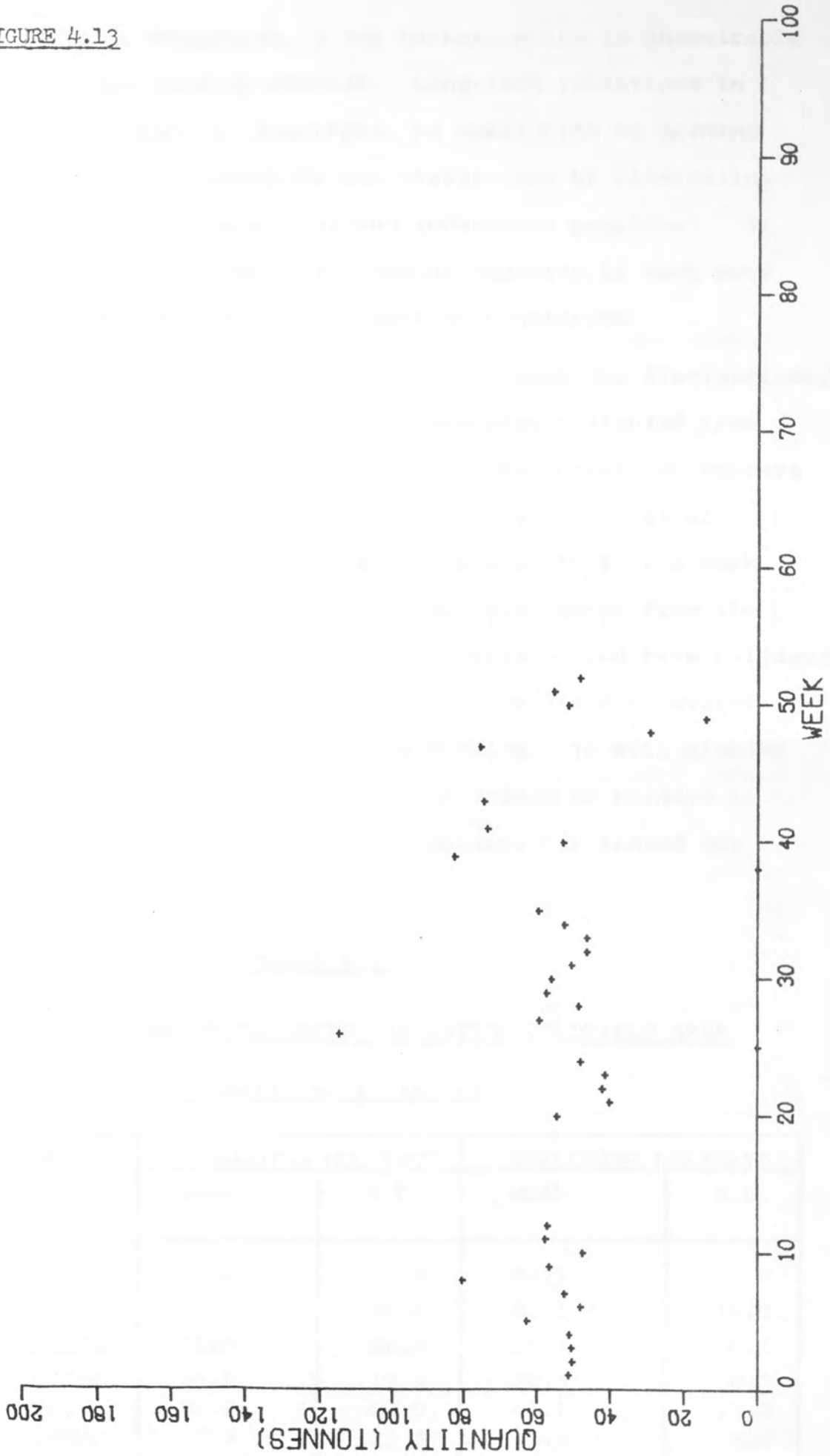
SUTTON WORKS DAILY COLLECTION - MON

FIGURE 4.12



SUTTON WORKS DAILY COLLECTION - FRI

FIGURE 4.13



will begin to decompose in the bunker, which is undesirable on health and amenity grounds. Long-term variations in the arisings cannot, therefore, be dealt with by holding stocks of refuse (which is the classic way of eliminating such problems in commercial and industrial practice). At the older plants, where the storage capacity is much more limited, shorter time-scales must be considered.

To give an indication of the scale of the fluctuations, Figures 4.12 and 4.13 show the quantities collected from the catchment area of the Sutton Coldfield works on Mondays and Fridays respectively, for a complete year. It will be seen that in addition to a moderate scatter from week to week, there are occasional large divergences from the normal level; these occur around Christmas and bank holidays, when the collection service does not operate for several days, and must then catch up the backlog. It will also be noted that the general level of collection on Fridays is substantially lower than that on Mondays (or indeed any other weekday).

TABLE 4.3

VARIATION IN WASTE COLLECTED IN SUTTON COLDFIELD AREA

All quantities in tonnes

<u>DAY</u>	<u>INCLUDING HOLIDAYS</u>		<u>EXCLUDING HOLIDAYS</u>	
	MEAN	S.D.	MEAN	S.D.
Monday	78.2	30.3	82.1	17.0
Tuesday	77.1	26.2	83.6	14.3
Wednesday	81.5	21.4	85.9	10.1
Thursday	86.6	19.9	90.6	8.5
Friday	52.7	20.0	53.9	13.0
Saturday	7.4	13.5	5.3	8.6
Week	386	70	393	57

Table 4.3 shows the mean and standard deviation of the collected quantities for each day of the week, and for the weeks in total, both including and excluding holiday periods. This exclusion of abnormal results was made by removing all data points which fell more than 2.5 standard deviations from the appropriate mean; only 1.2% of the points in a normal distribution fall outside these limits, and in fact all the points so excluded fell in the holiday periods, so this criterion seems reasonable.

The variation shown in these figures is substantial, ranging from 9.4% for Thursdays to 24.2% for Fridays and more than 160% for Saturdays (which are of course a special case). For complete weeks, the standard deviation is 14.5% of the mean, comparable to the variation in individual days, so storage from day to day will not eliminate the majority of the variation. This is not to suggest that the greater storage of the more recent plants is unnecessary - it is needed to allow the possibility of 24 hour/day working with normal collection, which is now being practised - but rather to point out that storage on this scale does not eliminate the effect of collection variability completely.

Some consideration must be given to the implications of such a variation of input for the operation of the plants, particularly with regard to the strategic planning which is the main object of this study. If a plant is to accept these variations in input, the peak input rate (for a day, assuming a day's storage in the bunker) must not exceed the peak capacity of the plant (roughly speaking). If the strategy is planned on the basis of average waste arisings and plant capacities on paper, it is likely that the plant

will sometimes be seriously overloaded, depending on how conservative the design ratings were. In the case of existing plants, the practice in West Midlands County Council is to use "budget" ratings based on experience of the plant's actual throughput, and these will obviously take account of the effects of the patterns of variation which occur. Some care is then needed when considering possible new plant, particularly of a new type, in order to allow for the effect of variation of input on the usable, as distinct from design, capacity. If this is not allowed for, new types of plant are likely to show an apparent advantage over the existing ones, which may not be obtainable in practice. Alternatively, peak plant capacities could be used, together with a "peak arisings" figure, which would indicate the largest arisings from a given area which the waste disposal system must deal with "normally"; this would, in effect, be a design capacity for the entire system. The latter approach seems rather less haphazard, and makes the assumptions more explicit. However, when dealing with landfill sites, the important factor is the average rather than the peak input; thus if a complete system is being modelled, some assumptions would be needed about the relationship of peak to average arisings, and (assuming some definite frequency distribution) this would constitute a decision as to the acceptable probability of overloading the system, which is clearly a policy issue. Indeed, some such assumption would be needed to obtain the "peak capacity" of the incinerators from their budget capacities, to allow for the other factors causing deviations from the design capacity. This decision has been avoided in the present work

by adopting the earlier alternative of using average arisings and budget capacities, since no new types of treatment have been considered; the only major new plant dealt with, the new Tyseley incinerator, is of a design well-known to WMCC staff, and it has been assumed that they are able to allow for these effects in deciding on the budget capacity for this new plant.

5. MODELLING WASTE MANAGEMENT ACTIVITIES

In this chapter, the various activities which are involved in operational waste management will be discussed and models of them will be produced. These will be very simple models, mostly resulting from straightforward interpretation of existing data; they are needed mainly as inputs to the overall models of the waste management system which will be discussed in chapter 6, although some insights may result directly. The aim is to remove as much as possible of the complexity apparent in day-to-day working, so that the relevant factors for strategic planning can be identified.

One of the main factors to be considered in assessing alternative strategies for waste management is their cost; because this particular factor has traditionally come under close control, unlike the environmental impact (for instance), there is relatively good information available on it, and for this reason it is the factor which has been considered in most detail in this research. It is assumed that the total cost of a waste management system will be the sum of the costs of various activities which are undertaken as parts of the system, and which are financially independent of each other. This chapter will discuss the costs to be attributed to each of the activities which are to be considered in the overall planning, and how costs which arise at different times can be combined. The reliability of activities will also receive some attention.

It has often been proposed that environmental impacts and other effects of waste management activities should be

taken into account in planning, by determining their significance in monetary terms. This is the technique of cost-benefit analysis, which has been applied to such problems as the siting of the third London airport (Kendall (1971); Plowden (1971)). Though in principle this approach is attractive, it does involve large-scale data collection and has not been attempted in the present research. Only actual monetary costs have been dealt with. However, neither the use of cost-benefit methods nor the neglect of non-monetary costs eliminates the need to consider precisely what expenditure (or rather whose expenditure) is to be counted as a cost for planning purposes.

The most obvious approach for a waste disposal authority is to count only those costs which it must meet directly out of its own funds - the costs of running its own vehicles, landfill sites, and so on, and the cost of any compensating payments it may make to collection authorities who must transport waste unreasonably long distances to disposal points (see section 1.3). However, it seems rather unreasonable not to take account of the costs incurred by collection authorities except where they are "unreasonable" in themselves - these costs will after all be borne by the same ratepayers. When industrial wastes are to be included, the problem is even more acute; should one consider the cost to the waste disposal contractors, the cost to local industry (due to the contractors' charges), the cost to the consumers (due to increased prices for manufactured goods),? The commonly used phrases such as "cost to the community" (section 3.2) tend to obscure the difficulties;

there are bound to be differences of opinion on such issues. For example, an extreme "environmentalist" might take the view that the only real social cost is measured in terms of the use of non-renewable resources (which could be determined using input-output analysis); another view might be that one should not talk about the total cost, but rather the distribution of costs through the community and their effect on the distribution of wealth. Clearly, therefore, what is to be counted as a cost is a political decision, together with the decisions about environmental and other effects of a proposal.

In this work, which has been concerned mainly with domestic waste, no serious difficulty has arisen, since all the costs are incurred by either the collection or the disposal authority. It has been assumed that the criterion to be used is that of total cost to all the authorities concerned, but the costs incurred by each authority are tabulated separately so that the distribution of costs between them can be examined for each proposal studied. However, if it should be required to extend this type of assessment to cover industrial wastes, there may be political complications concerning the interaction of the private and public sectors (Dept. of the Environment (1976h)). Although the overall models to be discussed in chapter 6 do not optimise the complete system, simply presenting the decision-maker with calculated costs for some sections of the community and not others is bound to influence the result (and there are so many possible sections that not all can be considered). Thus before extending the models to cover all wastes, careful consideration is needed to decide

just what costs will be taken into account in the final decision.

5.1 Models of Collection

Although this work is not concerned with collection as such, it is necessary to have some representation of the collection process in the overall model, in order to calculate transport costs. The actual organisation of collection rounds is an operational rather than a strategic decision, and is in any case the responsibility of the collection rather than the disposal authority. Although it is conceivable that a model could be produced to optimise the collection system for a given set of disposal points, such a model for a complete county would be very unwieldy (computational cost would probably be prohibitive if many disposal arrangements were to be considered), and might also cause political problems between authorities. It is therefore necessary to use some simple model to represent the collection system as well as possible.

There are four main points at which the model needs to simplify the real situation, and this simplification can be done in several ways. These points are:

- The use of several different types of vehicle for collecting different types of waste. These different vehicles will have different costs of operation, and work in overlapping areas. In principle, each type of vehicle could be treated separately, but for simplicity in this work they have all been aggregated.

- The discrete nature of the collection process, due to the need to empty the collection vehicle an integral number of times in a working day (it is undesirable for refuse to be stored in the vehicle overnight). This causes abrupt changes in cost if it is necessary to change the number of trips per day; the points at which these occur depend on the capacity of the vehicles in use, and thus differ from one type of vehicle to another. Also, the cost is not proportional to the amount of refuse collected - this causes difficulty with the overall model. These effects have therefore been ignored in this work, and collection treated as if it were a continuous process, represented simply by a fixed cost per tonne.
- Distribution of arisings in time. The arisings from a given area fluctuate significantly from one week to the next, and also may show long-term trends (these points are discussed in ch. 4). The way in which these effects are treated depends on the overall model - in this case discrete steps in time are considered, within which arisings are aggregated, but trends over the series of steps can be dealt with.
- Distribution of arisings in space. Arisings actually occur at each house or block of flats (considering only household waste), and clearly it is quite impracticable to deal with this level of detail for a whole county. The most obvious course is to aggregate into larger units, perhaps collection rounds (though it should not be assumed that the round system will not change within the lifetime of the plan), or even larger areas. This is the course usually adopted,

but an alternative is possible - to consider the arisings as continuous, represented by a "waste arisings density function" at any point in the county. This possibility does not appear to have been investigated previously, and will be discussed in section 5.1.1, while the aggregated discrete model will be examined in 5.1.2.

5.1.1 The Continuous Approximation

In this view, the arisings are considered to appear distributed continuously over the whole area to be dealt with. In order to calculate the transport cost, given the set of disposal points, some assumption as to the transport cost must be made, and the total cost can then be found by integrating over the area feeding each disposal point. The essential problem in this model is to delineate the areas which will be allocated to each disposal point in a least-cost transport system.

As a first step, consider a very simple case with the following assumptions:

- Transport cost is proportional to distance travelled and quantity carried;
- There are two disposal points, each of specified capacity (See later for an extension to more than two points);
- Arisings occur uniformly over the whole area, and total arisings exactly match total disposal capacity. This situation is shown in Figure 5.1. The solid line RPQ represents the boundary between the areas assigned to the two disposal sites A and B, which has been chosen so that the total transport cost is a minimum. Let the cost of transport to site A from any point be c_A , and similarly

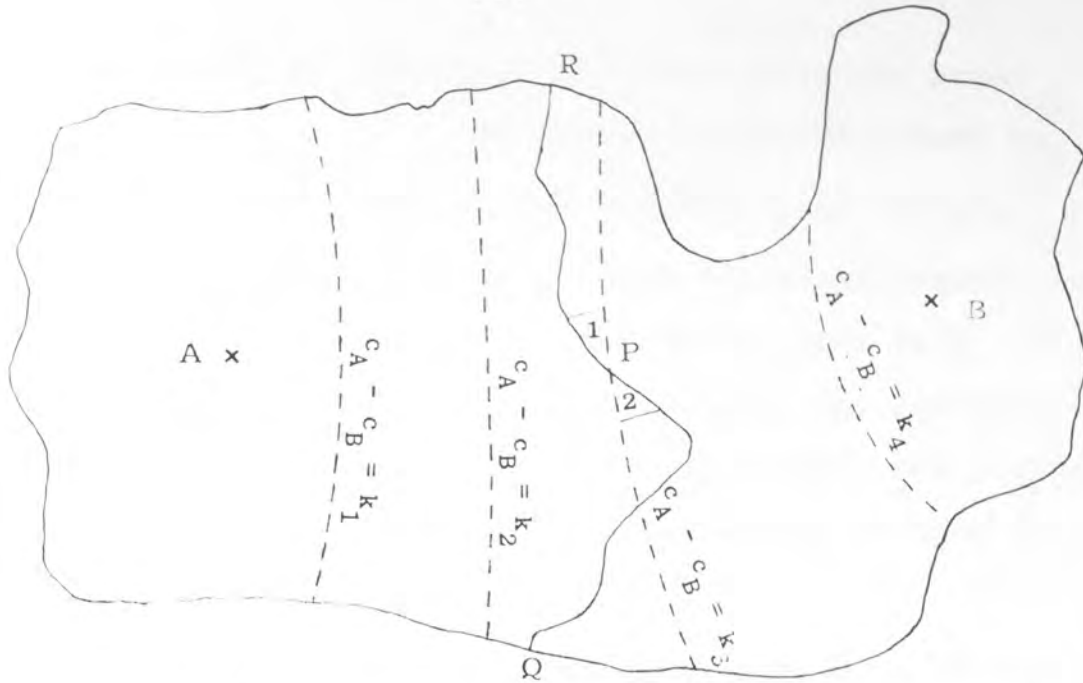


FIGURE 5.1. LINES OF CONSTANT COST DIFFERENCE

that to B be c_B . Then the cost difference $c_A - c_B$ is smallest in the neighbourhood of A, and increases as one approaches B. The broken lines in Figure 5.1 represent contours of constant cost difference k ; from the argument just given, $k_1 < k_2 < k_3 < k_4$. Now consider the intersection of such a contour with the boundary between the two areas, at P. Consider two small equal areas, one on each side of the intersection - the shaded areas 1 and 2 in the figure. Area 1 is assigned to disposal site B, and area 2 to A. Let the transport costs from the two areas to the two disposal points be ${}_1c_A, {}_2c_A, {}_1c_B, {}_2c_B$. Since area 1 lies to the left, and area 2 to the right, of the constant cost line, it is clear that ${}_1c_A - {}_1c_B < k_3$ and ${}_2c_A - {}_2c_B > k_3$. The total transport cost from the two areas assigned as shown is ${}_1c_B + {}_2c_A$. Now suppose the boundary to be redrawn so that area 1 is assigned to A and area 2 to B. Since the areas are equal, and thus produce equal arisings, this will not alter the quantities dealt with by the disposal

points; the total transport cost from these two areas will then be ${}_1c_A + {}_2c_B$. The increase in cost caused by this change is thus $({}_1c_A + {}_2c_B) - ({}_1c_B + {}_2c_A) = ({}_1c_A - {}_1c_B) - ({}_2c_A - {}_2c_B)$. But since from above the first bracket is less than k_3 while the second is greater, this is a negative number and the change in boundary has actually produced a decrease in cost. This contradicts the initial assumption that the boundary has been chosen to give the least possible cost.

Since consideration of the intersection of the boundary with a line of constant cost difference has led to a contradiction, there can be no such intersections. Thus the boundary giving the minimum total cost must itself be a line of constant cost difference. What the actual value of the cost difference will be on the boundary depends on the capacities of the plants; it must be chosen so that the area assigned to each disposal point matches its capacity.

We must now determine the shape of the contours of constant cost difference. Let A be the origin of a set of rectangular cartesian co-ordinates, and B lie on the x axis at $(2d,0)$ (Figure 5.2). The point (x,y) is on the contour of cost difference $2k$. Since we assume that the transport cost is proportional to the distance (arising being uniform over the whole area, the dependence of cost on quantity transported is irrelevant), this is also a contour of constant difference of distance from A and B. Let the cost per unit distance be q ; then the difference in distance is

$$\sqrt{x^2 + y^2} - \sqrt{(2d-x)^2 + y^2} = 2k/q \quad \dots (5.1)$$

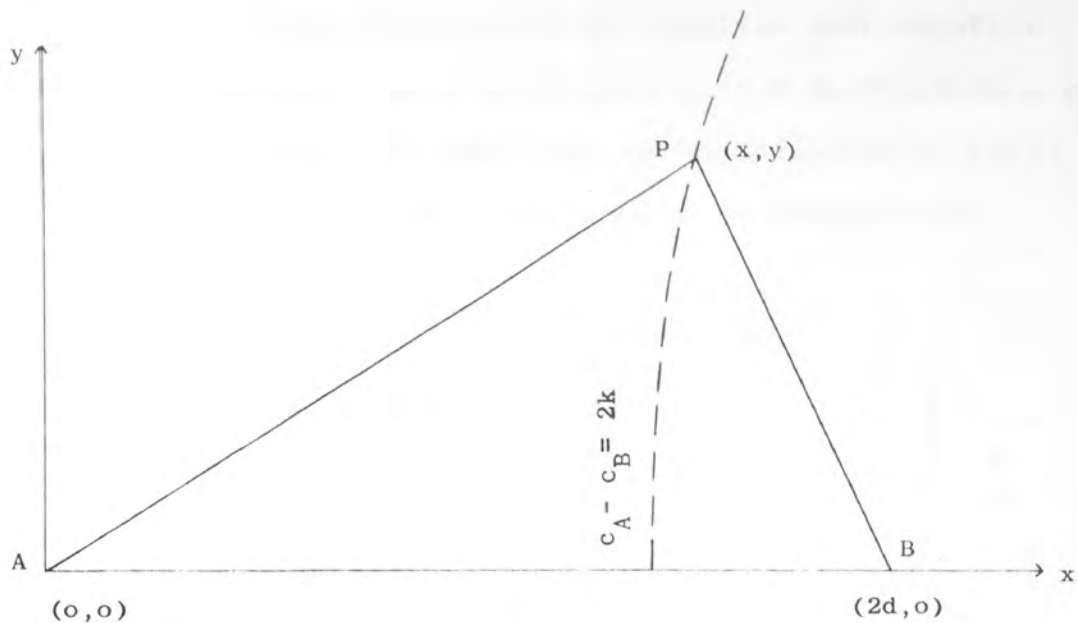


FIGURE 5.2 SHAPE OF A CONTOUR OF CONSTANT COST DIFFERENCE

which reduces to

$$\frac{(x-d)^2}{k^2/q^2} - \frac{y^2}{d^2 - k^2/q^2} = 1. \quad \dots(5.2)$$

This is a hyperbola, symmetric about the x axis (as one would expect). Note also that in the special case $k=0$ the result is that $x=d$, which is a straight line perpendicular to the x axis, midway between A and B. This again would be expected intuitively. If $k/q > d$, the curve would be an ellipse; but this case is not relevant, being an artefact of the derivation. We can see that this is not a solution of the original equation (5.1), since considering the triangle APB in Figure 5.2,

$$AP < AB + BP,$$

i.e.

$$\sqrt{x^2 + y^2} < 2d + \sqrt{(2d-x)^2 + y^2}$$

$$\text{or } \sqrt{x^2 + y^2} - \sqrt{(2d-x)^2 + y^2} < 2d,$$

and substituting from (5.1),

$$2k/q < 2d.$$

The curve (5.2) is also symmetric about $x=d$, i.e. it has two branches. These correspond to positive and negative values of k , and are again artefacts of the derivation - only k^2 appears in (5.2), but the sign is significant in (5.1), where the positive square roots should be understood.

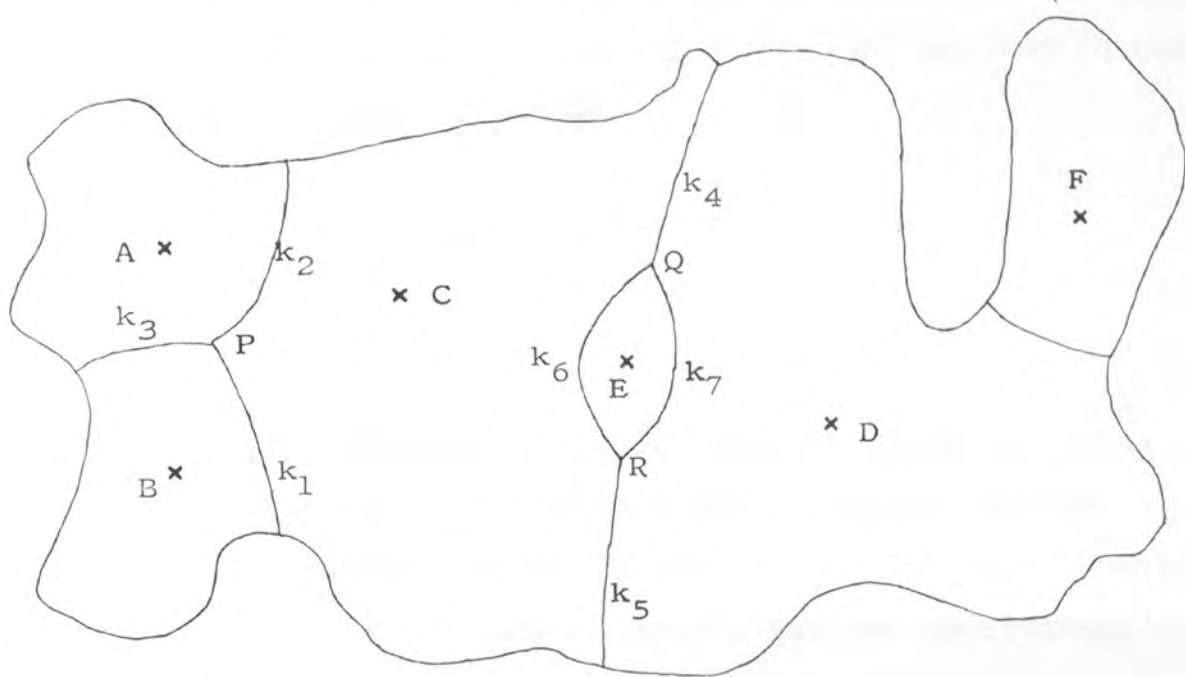


FIGURE 5.3 BOUNDARIES WITH MORE THAN TWO DISPOSAL POINTS

In an area where there are several disposal points, the subdivision will be relatively complex, as in Figure 5.3. From the same argument as that used above in the case of two points, it is clear that the boundary between the areas served by any two points in the more complex case will be the constant cost difference hyperbola as before. Where boundaries intersect, as at P in Figure 5.3, we can derive a relationship between the cost differences from this. Denoting the cost from this point to A, B, C by c_A , c_B , c_C respectively, we have:

$$\begin{aligned} c_B - c_C &= k_1 \\ -c_A + c_C &= k_2 \\ c_A - c_B &= k_3 \end{aligned}$$

and so adding, $k_1 + k_2 + k_3 = 0 \dots (5.3)$

with suitable choice of signs for the k's. Where the boundary between the areas assigned to two disposal points falls into more than one part, as with the boundary between C and D in Figure 5.3, each part has the same cost difference, as can be seen by considering equation (5.3) applied to each of the intersections P and Q:

$$\begin{aligned} k_4 + k_6 + k_7 &= 0 \\ \text{and } k_5 + k_6 + k_7 &= 0 \\ \text{so } k_4 &= k_5 \end{aligned}$$

The requirements for using this method to estimate the transport costs for a county with a complex system of waste management can now be seen in outline. The boundary between each pair of disposal points must be considered; with n points, there are $\frac{1}{2}n(n-1)$ possible boundaries. The intersections of these with each other and the boundaries of the area must be found; there are $2(n-1)$ actual intersections, but there are many more possible ones which do not appear in the final picture. Those boundaries and intersections which do actually appear must be found by adjusting the area assigned to each point so that its capacity is taken up; this will require numerical integration over the relevant areas, and when adjusting each area the condition (5.3) must be taken into account at each intersection on its boundaries. This will clearly be a fairly complex computation, and one without obvious connections with other standard problems. Also the effect of varying arisings over the area, and of disposal points without fixed capacity, have not yet been considered. Thus a

considerable amount of effort would be required in any attempt to use this approach, in order to produce an algorithm for solving this problem. In contrast, the use of discrete "centroids" of arisings, as described in the following section, allows the use of standard transportation and linear programming algorithms. The discrete method was therefore used in the remainder of this work.

5.1.2 The Discrete Approximation

In this approach, the arisings from an area are assumed to appear at a particular point which is in some sense at the "centre" of the area. The usual term used is "centroid", meaning the "centre of gravity" of the arisings. This probably gives a misleading impression that the point is well-defined, since the true centroid can only be found on the basis of data about the distribution of the arisings on a more detailed level, which are not usually available. The geographical centre of the area may be used, assuming in effect that the arisings appear uniformly over the whole area; in the present work, the points were chosen by examining an Ordnance Survey map (1:50 000 scale) of the area, and judging by eye the centre of the built-up parts, thus making some allowance for the non-uniform distribution of population. The county was divided into 23 collection areas; their boundaries and "centroids" are shown in Figure 5.4, and the assumed quantity of waste arising at each point is given in Table 5.1.

The purpose of identifying these points is to use them to estimate the transport costs to the disposal sites. This

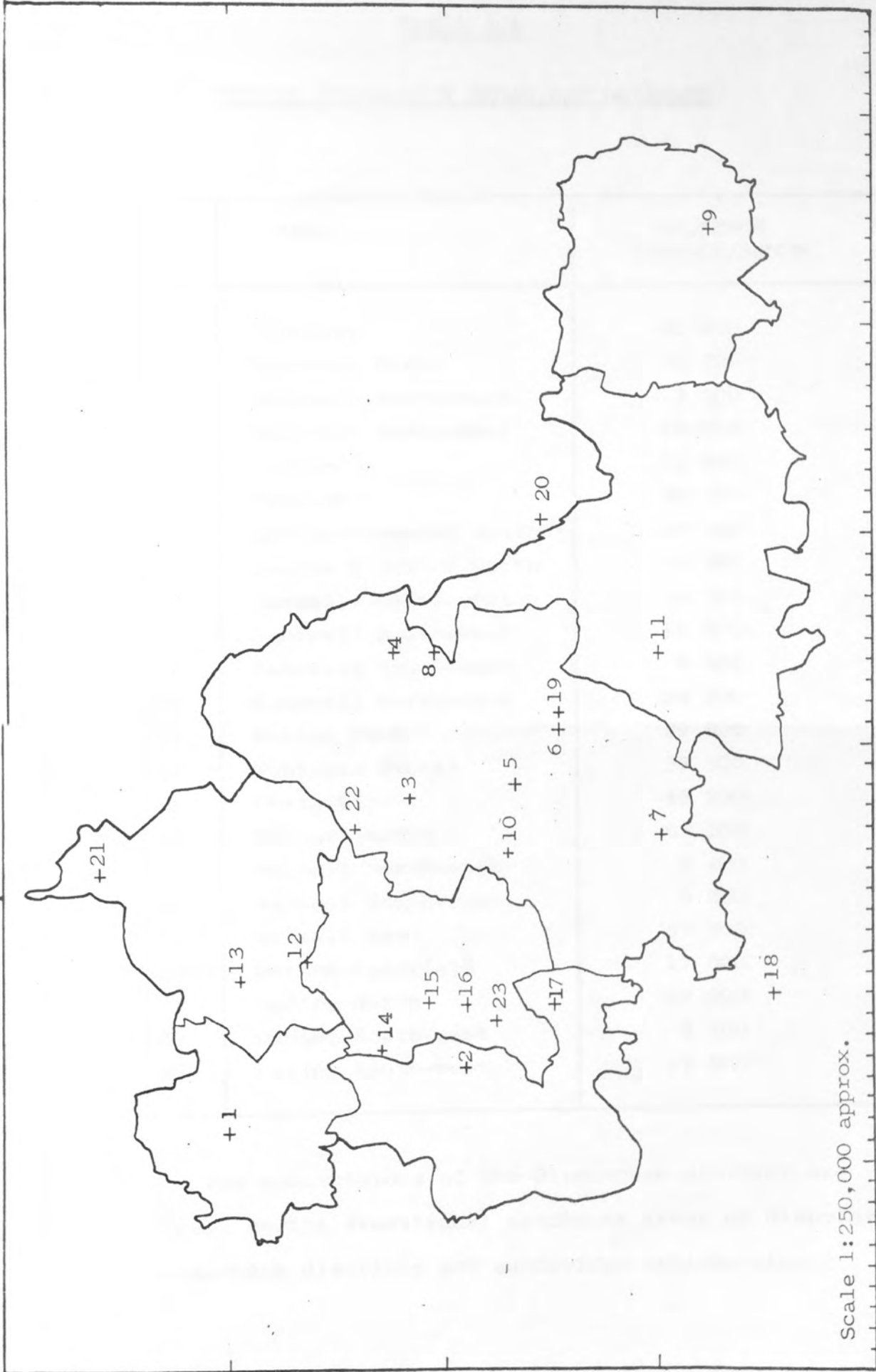


FIGURE 5.4 COLLECTION AREAS AND CENTROIDS FOR MODELLING PURPOSES

was done by measuring the distances along a likely route, and estimating the speed of the vehicles along that route (since it had been decided to base the estimates of transport costs on travel time rather than distance - see the next section). This procedure was very time-consuming, and its use resulted in the measurement and inclusion as possible routes of only the more plausible combinations of collection area and disposal site. It was adopted because it was felt that the variety of road conditions within the West Midlands would result in a wide range of transit times for any given distance "as the crow flies". The positions of current disposal sites, listed in Table 5.2, are shown in Figure 5.5. The resulting travel times are shown in the listing of the computer input data (Appendix D).

It is more common in the literature to adopt some method of estimating the travel time or distance from the locations of the two points concerned. If this is done, it is only necessary to supply the positions of the centroids and disposal sites (probably as National Grid co-ordinates), and the time or distance can easily be calculated by computer. Since a computer will be needed to deal with the overall model in any case (see chapter 6), this is very convenient. It was therefore decided to compare the result of using such a method with the manual estimates, to see how accurately the simpler process could represent conditions in a complex urban area.

The usual method of estimating the travel distance (and hence by assuming a constant speed, the travel time)



Scale 1:250,000 approx.

FIGURE 5.5 POSITIONS OF WASTE DISPOSAL FACILITIES IN WEST MIDLANDS

TABLE 5.1REFUSE COLLECTION AREAS AND ARISINGS

NO.	AREA	ARISINGS (TONNES/ANNUM)
1	Coventry	91 400
2	Solihull North	20 700
3	Solihull South-east	3 300
4	Solihull South-west	45 000
5	Lifford	52 800
6	Tyseley	34 700
7	Castle Bromwich South	48 100
8	Castle Bromwich North	4 300
9	Sandwell North-west	14 200
10	Sandwell South-west	16 800
11	Sandwell South-east	6 600
12	Sandwell North-east	28 200
13	Rotton Park	29 800
14	Montague Street	39 500
15	Perry Barr	48 200
16	Wolverhampton	63 300
17	Walsall North-east	3 400
18	Walsall South-east	6 800
19	Walsall West	57 300
20	Sutton Coldfield	17 800
21	Dudley North	37 000
22	Dudley South-east	9 700
23	Dudley South-west	11 500

The subdivisions of the Birmingham district are based on the traditional catchment areas of disposal plants; elsewhere districts are subdivided arbitrarily.

TABLE 5.2WASTE TREATMENT AND DISPOSAL FACILITIES

NO.	FACILITY
	<u>INCINERATION PLANTS</u>
1	Wolverhampton
2	Dudley
3	Perry Barr (also IMI plant)
4	Sutton Coldfield
5	Montague St.
6	Tyseley (old and new works)
7	Lifford
8	Castle Bromwich
9	Coventry
	<u>TRANSFER STATIONS</u>
10	Rotton Park St.
11	Solihull (temporary)
12	Walsall/Sandwell (hypothetical)
	<u>LANDFILL SITES</u>
11	Hay Lane
13	Bentley Lane
14	Barnfield Rd.
15	Tividale
16	Blue Rock Quarry
17	Mucklow Hill
18	Marlbrook (residue only)
19	Speedwell Rd. (emergency only)
20	Packington (private site)
21	Birch Coppice (possible)
22	Booth's Lane (possible)
23	Allsopp's Quarry (possible)
24	Long haul site (hypothetical)

is to use an L_p metric (Kuhner and Heiler (1973)). This represents the distance between A and B as

$$L_p = \left[(x_A - x_B)^p + (y_A - y_B)^p \right]^{1/p}$$

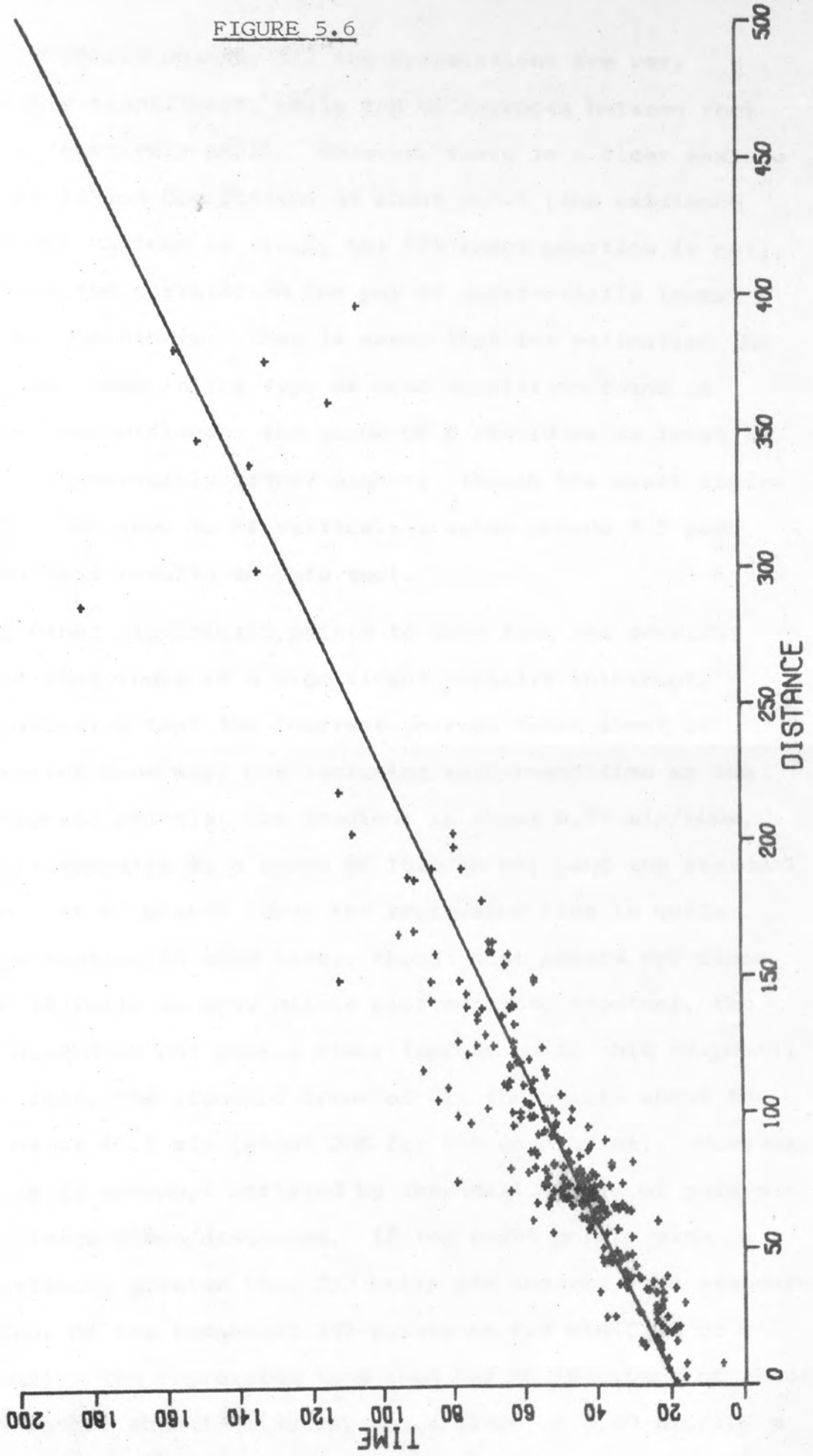
The usual way of using this metric is to choose either $p=2$ (the straight-line Euclidean distance) or $p=1$ (assuming an L-shaped path, appropriate in North American cities laid out in a grid pattern), according to the area. It was thought that an intermediate value of p might give a better representation of conditions in the West Midlands, so a range of values of p was tried, and linear correlations calculated between the distances calculated from the L_p metric and the time estimated manually. The results are shown in Table 5.3 and Figure 5.6. The time units are minutes, and those for distance are hundreds of metres.

TABLE 5.3 TEST OF L_p METRIC FOR TRAVEL TIME ESTIMATION

p	Correlation Coefficient	Gradient	Intercept
1.0	0.881	0.261 ± 0.009	19.6 ± 1.3
2.0	0.911	0.341 ± 0.010	18.6 ± 1.1
3.0	0.914	0.357 ± 0.010	18.8 ± 1.1
3.5	0.914	0.361 ± 0.010	18.9 ± 1.1
4.0	0.914	0.362 ± 0.010	18.9 ± 1.1
5.0	0.913	0.364 ± 0.010	19.1 ± 1.1

FIGURE 5.6

TEST OF L3.5 TIME ESTIMATE



With 255 points, all the correlations are very highly significant, while the differences between them are relatively small. However, there is a clear maximum correlation coefficient at about $p=3.5$ (the existence of the maximum is clear, but its exact position is not), while the correlation for $p=1$ is substantially lower than the others. Thus it seems that for estimating the travel time in the type of road conditions found in the West Midlands, the value of p should be at least 2 and preferably rather higher; though the exact figure does not seem to be critical, a value around 3.5 gave the best results in this test.

Other significant points to note from the results are that there is a significant positive intercept, indicating that the shortest journey takes about 19 minutes (one way, not including turn-round time at the disposal point); the gradient is about 0.36 min/100m, corresponding to a speed of 16.6 km/hr; and the residual scatter of points about the regression line is quite substantial in some cases, though most points are close to it (with so many points plotted close together, the figure does not give a clear impression in this respect). In fact, the standard error of all the points about the line is 10.2 min (about 20% for the mean point). However, this is somewhat inflated by the small number of points at large times/distances. If the eight points with distances greater than 250 units are ignored, the standard error of the remaining 247 points is 8.3 min (17% of mean). The regression line then has an intercept of about 16 rather than 19 minutes, and a slope of 0.40 min/100 m (corresponding to a speed of 15 km/hr). The change in

both parameters of the regression line is several times the standard error of the estimates, so these few points clearly have a significant effect on the regression. This gives some indication that the "true" line of travel time against distance would level off to some extent at large distances, rather than being a straight line. However, it was not possible to pursue this line of investigation any further in the present study.

The fact that even the shortest trip takes a significant time may be found rather surprising, but this is due to the procedure used when making the manual estimates of travel time. In some cases, the centroid of a collection area fell very close to a disposal point; the manual measurement of distance was then made from further away, at a point more typical of the area in its distance from the disposal point (on a purely subjective basis). It is clear that in an extreme case, the disposal site might lie at the centroid of its district, but this would obviously not mean that transport costs would be zero. Thus the distance between the centroid and the disposal site does not represent a typical distance of travel for a collection vehicle when this distance is small, and the result of the correlation is quite realistic. The size of this effect depends on the size of the districts - if the centroids of individual collection rounds were used, the minimum cost of transport could be zero.

The conclusion from this is that it is possible to use an L_p metric to give reasonable estimates of travel times. Some allowance for the distorting effect of the use of

centroids for short distances should be made, for instance by including a constant minimum time rather than assuming time to be proportional to distance (it is possible that a non-linear relationship between time and distance could be found to give a better fit, but this was not attempted). Since individual trips may not be well represented, it is preferable to make manual estimates, allowing for varying road and traffic conditions, in critical cases; but if a general impression for a large number of different trips is required, the metric will give this without requiring much effort to provide the data.

5.2 Models of Transport

The overall models to be discussed in chapter 6 are essentially concerned with transport arrangements, so it is important that the costs of transportation are represented as well as possible. This section will discuss the general problems of modelling the cost of transport in this field, and the derivation of actual cost figures for use in the overall calculations.

One basic decision which must be made is whether to assess the cost of a given trip on the basis of the distance or the time taken. In practice it would not be feasible to time each trip, so if the time is used, it must be estimated from the distance by assuming an average speed, or some more complex relationship (see section 5.1.2). The distance can be found easily from a map, or estimated from the grid references of the end points. Thus there is slightly more effort involved

in using the trip time rather than distance. On the other hand, some of the main components of the cost (e.g. labour, interest charges on the vehicles) clearly depend on the time rather than the distance run; and in urban conditions, low speeds over short distances probably result in as much fuel consumption, mechanical wear and so on as higher speeds over greater distances. It is therefore felt that the time is a more realistic measure of the costs incurred, in conditions where the speed attained varies considerably from one trip to another, and the trip time was used as the basis for this work. The way in which the time for a given trip was estimated is described in section 5.1.

As noted above (section 5.1), collection is a discrete process, and the same applies to transport, whether in collection vehicles or in bulk vehicles after transfer. However, the present work is concerned with planning on a large scale in both time and space, and for practical reasons the discrete nature of the processes has been ignored. This is significant when relating the cost of a given journey to the travel time. Aggregating over all vehicles, and ignoring the requirement that an integral number of trips must be made in a working day, the cost can be represented by a simple figure for the cost per tonne-minute of transport. This figure can be obtained from the records of expenditure on the existing collection vehicle fleet, for collection vehicles; for bulk vehicles and those used for transporting residue, either similar records (if available) or standard estimates of cost for comparable commercial operations (e.g. Commercial Motor, 1977) can be used. (Since refuse collection vehicles

are very specialised, and not readily comparable to any commercial vehicle, the latter approach seems inappropriate in their case, and records should always be available).

If it is assumed that the number of trips per day made by a collection vehicle is fixed, as is the operating cost per day, then it is easy to show that the cost per tonne for a trip taking time t is proportional to $(1 - Bt)^{-1}$, where B is a constant. This is linear in t for small Bt , but increases more rapidly as t approaches the limiting point at which $Bt = 1$, for which the cost is infinite. This corresponds to a journey time so long that no time is left for collection. In practice, changes in the number of trips made per day, and in the number of collectors per vehicle (affecting the loading rate) can largely offset this. Furthermore, the stated effect assumes that no productive work goes on while the vehicle is away - this is not usually the case, though clearly with very long trips there would be a limit to the preparatory work that could be done while waiting for the vehicle to return. These effects tend to reduce the dependence on travel time towards a more linear variation, and in this work such a variation has been assumed. For a discussion of the above relationship, see Wilson (1978).

With bulk haulage, the situation is rather different. The vehicle spends nearly all its time travelling, rather than collecting its load, and the load carried does not depend on the time spent collecting (it is assumed that there will always be a load waiting when the vehicle arrives). In these circumstances, and since transfer

and bulk haulage are likely to be used when the journey times are relatively large compared with those for collection vehicles, the requirement for an integral number of trips per day may become important. This will mean that, since much of the cost of a haulage operation depends only on the number of vehicles and drivers required, and not on the time for which they are actually on the road, the cost of the operation is almost independent of the journey time over limited ranges, and changes suddenly if the time is increased so that one less trip per day becomes possible. Again, there are practical ways of smoothing out this effect - for instance, a small amount of overtime working. Although transport of this nature, from discrete sites rather than collection areas, is more amenable to such forms of relationship, a continuous variation with travel time has been assumed in the present work.

Table 5.4 shows the costs for several different types of vehicle used by Birmingham District Council for waste collection. The "vehicle cost" quoted includes fuel, maintenance and depreciation, but not the cost of wages, per operating day. Assuming a cost of £20 per day for driver's wages and associated costs, and a 7-hour effective working day (allowing for crew breaks, etc.), gives the "cost per vehicle hour". These figures range from £5.91 to £7.89, and date from the second quarter of 1976. Figures quoted by the other districts in late 1975 range from £5.12 to £7.50 for the average cost per vehicle hour, including driver (other assumptions made in deriving the

latter figures are not known), so this seems a reasonable range. The rate of inflation is indicated by the fact that the most expensive type of vehicle used in Wolverhampton cost £3.37 per hour in the financial year 1973-4; thus cost figures in this area are very quickly outdated. The average loads quoted (in tonnes) are taken from earlier Birmingham data, and dividing by these figures gives the cost per tonne-hour; the cost per tonne-minute is shown in the table.

TABLE 5.4 OPERATING COSTS OF WASTE COLLECTION VEHICLES

VEHICLE TYPE	VEHICLE COST (£/day)	COST PER VEHICLE HOUR (£)	AVERAGE LOAD (t)	COST PER TONNE-MIN (p)
Dustless	31.88	7.41	3.56	3.47
Bulk	31.66	7.38	2.42	5.08
Dennis Paxit	35.22	7.89	3.10	4.24
Dennis Collectomatic	21.37	5.91	3.23	3.05
Seddon Collectomatic	23.70	6.24	3.65	2.85
Revopak	24.00	6.29	2.45	4.28

The average loads quoted are mostly well below the "capacity" of the relevant vehicle, in the sense of the maximum it can carry at one time. However, it is not possible to operate the collection system in such a way that vehicles are always filled; it is almost inevitable that part loads will be left at the end of the day, and

thus there is no way to use the capacity of a vehicle to the full. Consequently, the average load, which reflects the "efficiency" of the collection system in filling the vehicles, is a better measure to use in this case. The average load will of course depend to some extent on the disposal system in use, in particular on the travel time to the disposal site - this is a result of the need, noted above, to make the trip an integral number of times in a day. Since this effect is assumed to be averaged out by the variety of vehicles and individual trips, the effect on the average load has also been neglected - it is assumed that the proportion of vehicle theoretical capacity that is actually used will be unaffected by changes in the disposal system. This may imply re-organisation of the collection system when the disposal system is changed.

This raises the question of "what is a cost" again, in a slightly different way. The organisation of the collection system is the responsibility of the district authorities, rather than the county. By suitable organisation, it is possible to alter the cost per tonne-minute of transport over a wide range. A particularly acute case is that of Birmingham, where it is usual for the entire collection crew to travel with their vehicle to the disposal site, rather than just the driver (as in the other districts of West Midlands). This results in the cost per vehicle hour, allowing for the wages of the collectors, being roughly twice that of the other authorities. Should the County Council use the full cost in making their strategic plans, or should they

regard the additional expense as being due to District Council policy and not a county responsibility? The same question could be raised with respect to the average load carried by collection vehicles - it is affected by County Council decisions, but is much more sensitive to decisions of the District Councils. In this work, a single figure for the cost per tonne-minute of all collection vehicles, regardless of the district which operates them, has been used, so such variations have been ignored. If required, however, it would be quite possible to allow for different transport costs in the different districts.

The variation found in the actual loads carried by collection vehicles is shown by the records of test weighings of individual vehicles carried out at the private landfill site at Packington, which was used to determine the average weight carried onto the site by these vehicles. Two different types of 40 cubic yard compression vehicles carried respectively 4.0 ± 0.9 and 4.3 ± 1.0 tonnes (ranges quoted are standard deviations), while 25 cubic yard vehicles carried 2.5 ± 0.7 tonnes and Dumpster container vehicles 0.84 ± 0.25 tonnes.

With such considerable uncertainties in the quantities carried by vehicles, it is clear that a very precise figure for the cost per tonne-minute cannot reasonably be given. The weighted average of the costs in table 5.4 (weighting based on recorded ton-miles run in a previous year) is 3.5 p/tonne-min, at July 1976 prices. Wilson (1978) estimates the cost at 17.8 p/tonne-km for a haul speed of 20 km/hr, measuring the one-way distance

only; this corresponds to 3.0 p/tonne-min. Thus the figure seems to be of the right general order of magnitude. Allowing 20% increase per annum, the mid-1977 figure would be 4.2 p/tonne-min.

These figures are based entirely on the situation in Birmingham. The average distance from collection to disposal points was quoted as 2.48 miles for Birmingham in late 1975; the corresponding figures for the other districts ranged from 2.69 to 5.96 miles. (These figures are quoted to surprising accuracy - their precise significance is not known). It is thus possible that the costs for Birmingham are not entirely representative of the West Midlands as a whole. From these figures (table 5.5) it appears that the cost per hour of collection vehicles increases with increasing distance to disposal. The figures for Birmingham, since they include the cost of the entire collection crew, must be ignored in this comparison. This might be due to a tendency to use larger vehicles for longer journeys - figures for the average vehicle load in each district are not available - or it might be that longer journeys result in less favourable operating conditions for the vehicles, and thus greater fuel consumption, maintenance, etc. (possibly maintenance is carried out on a schedule based on mileage rather than time?). However, these data are quite inadequate to come to any usable conclusion on this sort of issue, and it will be assumed that the Birmingham data do represent the whole of the county.

TABLE 5.5 COLLECTION COSTS IN THE DIFFERENT DISTRICTS OF
WEST MIDLANDS

DISTRICT	NORMAL AVERAGE DISTANCE TRAVELLED (miles)	AVERAGE SPEED OF COLLECTION VEHICLE (mi/hr)	AVERAGE VEHICLE OPERATING COSTS (£/hr)
Birmingham	2.48	12	11.81*
Solihull	4.43	16	6.30
Wolverhampton	2.69	10	5.12
Dudley	4.1	18	5.60
Coventry	5.96	17	7.50
Walsall	3.0	20	5.38
Sandwell	2.94	12	-

* This figure includes the full collection crew; others include the driver only.

Figures are taken from a W.M.C.C. internal report, and were obtained from district authorities. The way in which they were calculated is not known and may not be the same for each district.

For the bulk vehicles used to transport the output from transfer stations and incinerator plants, the fact that they are maintained under agency arrangements with district authorities makes it difficult to obtain detailed information on costings. Estimates produced by W.M.C.C. in mid-1977 were that Rolonof bulk vehicles had a standing cost of £9575 per annum, plus running costs of 38.36 p/mile, based

on 15 000 miles per annum. This is a total of £15329 per annum; assuming operation 8 hours per day for 250 days per year, the cost is 12.77 p/min, or 1.28 p/tonne-min for a typical payload of 10 tonnes. On the other hand, assuming 15 000 mi/a, the total cost per mile is 102.19 p, which for a plausible speed of 15 mi/hr and a 10 tonne payload as before gives a cost of 2.55 p/t-min. This factor of two discrepancy is at first sight rather startling; it is due to the fact that the vehicles spend only about half their time actually travelling (the remainder being spent in loading and unloading procedures), so that assumptions based on mileage give a misleading result. The former figure of 1.28 p/t-min is obtained in a way more nearly comparable to that used for the figures on collection vehicles, and so it seems preferable to use it in order to make a fair comparison. Increasing the distance travelled will (presumably) not increase the proportion of the time for which the vehicle is on the road; this argument also suggests that the lower figure, based on time rather than mileage, is the more appropriate.

It is interesting to compare the figures quoted with those of Commercial Motor (1977) for similar vehicles; it will be seen that they are very much higher. This might be attributed, in the case of the running costs, to the relatively high proportion of time spent in loading and unloading, and in the case of standing costs, to the high initial cost of the specialised vehicles. The main factor, however, is the low mileage covered by

these vehicles, relative to similar vehicles in commercial use, which results in relatively high costs per mile.

5.3 Models of Existing Treatment Plants

When incinerator plants, transfer stations or other types of waste treatment plants are already in use, it is possible to obtain historical data on the costs of their operation and maintenance. Such information is, however, insufficient to produce a plan for the future use of such plants, not only because the costs are likely to change with time (because of the difficulty of forecasting such changes more than a few months in advance, this point is almost invariably ignored in planning), but because it may be desirable to change the amount of refuse dealt with by a particular plant, or some other aspect of its operation. The effect of such changes on the operating costs can only be assessed by using a model.

The most obvious approach to this problem is to assume that the operating cost of a plant is proportional to the quantity of refuse dealt with, and to derive a cost per tonne from the records, which will be assumed to hold whatever the number of tonnes processed (perhaps within some limits). Clearly, when discussing existing facilities, the capital costs of the facility should not be included in such an assessment, since this expenditure is already committed regardless of the use made of the plant. It is less obvious, however, that some of the other costs of a plant are not proportional to the quantity

processed. Probably the most important of these is the cost of labour. The number of people required to run a plant is largely determined by plant design, and a reduction of, say, ten per cent in the quantity of waste dealt with will not make it possible to reduce the workforce by the same factor. A reduction of any magnitude would be possible only by reducing the number of shifts worked, or (in a multi-stream plant) the number of streams in operation.

Table 5.6 shows the budgeted operating cost for plants in the West Midlands for the financial year 1976-7, together with the proportion of these costs which can plausibly be assumed to vary with the amount processed. These items include electricity, water (in those plants where it is used for gas cooling), repairs and maintenance on the plant (but not the buildings), equipment, tools and materials. It will be seen that such expenses form a moderate proportion of the cost of operating direct incineration plants, but a smaller fraction of the cost of separation/incineration. This is because the latter, older-type plants have relatively large labour forces, and consequently their total operating costs are higher. The average cost per tonne for the four separation plants is £1.50, only slightly below that for the four direct incinerators (£1.85). The "throughput" of the plants given in the table is that actually recorded during the financial year, except for Tyseley and Montague Street, where the figures were extrapolated from a shorter period.

None of the costs detailed in table 5.6 includes the

income from the sale of the ferrous metals recovered from the refuse, or from processing trade wastes for which charges are made. The sums involved for all plants together were assessed at £140000 and £70000 respectively for the financial year 1976-7, and so are relatively small. However, the Coventry plant, which is not included in the table, is a special case in that heat is recovered from the combustion of refuse. Since a contract for the supply of a specified amount of heat exists, and the demand varies seasonally, assessing the costs of a change in the input of refuse to this plant is a complicated problem. In practice, since the alternative source of the heat (fuel oil) is so expensive, it has been thought worthwhile to transport waste a substantial distance to avoid a shortage. The additional cost of oil due to a shortage of refuse was estimated (in 1976) at about £4.50 per tonne of refuse; thus the cost per tonne for this works could be considered to be £4.50, in a limited sense (though the works might be physically capable of burning even more refuse, the benefits would not increase in proportion beyond the design input rate). This makes no allowance for the actual operating and maintenance costs of the plant; it has not been in operation for long enough for these to be well established.

It was argued above that, in order to realise significant savings on the cost of labour at plants, it would be necessary to reduce the number of shifts per day or the number of streams in operation. A rough estimate of the savings that this might provide was

obtained by considering the costs of a hypothetical 120000 tonnes per annum incinerator plant. At late 1975 prices, it was estimated that the total operating costs for one, two and three shift working would be £167000, £255000 and £339000 per annum respectively; assuming that 40000, 80000 and 120000 tonnes per annum would be processed in the three cases, the costs per tonne would be £4.18, £3.19 and £2.82 respectively. These figures must, of course, be inflated considerably to comparable with those in table 5.6, which are much more recent. The saving per tonne not processed is £2.15, according to the figures just quoted; allowing 50% inflation, this corresponds to £3.22 per tonne. This is about twice the saving for direct incinerators on those costs which were assumed to vary continuously with throughput, as estimated above. The effect of the labour cost is clearly significant, even though not all the labour costs are reduced by reducing the number of shifts worked (supervisory staffing is not necessarily reduced).

TABLE 5.6 ANNUAL OPERATING COSTS OF SOME WASTE TREATMENT PLANTS

PLANT	TOTAL OPERATING COST (£)	THROUGHPUT (tonnes)	COSTS PROPORTIONAL TO THROUGHPUT		
			(£)	(% of total)	(£/t)
Perry Barr	491910	77483	163540	33	2.11
Sutton C.	153540	16667	72470	47	4.35
Wolverhampton	256590	72373	74870	29	1.03
Dudley	225730	46249	82810	37	1.79
Castle Brom.	467610	52222	95150	20	1.82
Tyseley (old)	288270	36300	32360	11	0.89
Montague St.	309610	24400	43850	14	1.80
Lifford	364860	48943	72340	20	1.48
Rotton Park	117210	50000	9700	8	0.19

In all these figures, some simple assumptions have been made about the effect of changing throughput on plant maintenance costs. In practice, this effect is likely to be quite complex. When a plant is run continuously (3 shifts per day), it is less often subjected to the heating and cooling associated with start-up and shut-down; this should result in lower maintenance costs for the refractories, in particular, despite higher throughput. The refuse handling equipment, on the other hand, is subjected to wear which is proportional to the amount processed. No investigation of the importance of the different effects on the total cost is known, so simple assumptions must be made. It is likely that the effects would depend to some extent on the design and operation procedures of individual plant. If start-up and shut-down are frequent for reasons other than the end of the scheduled operation (i.e. for repairs to some part of the plant, or because of lack of refuse), there is little point in considering the effect of one such cycle per day. It is known that the pyrolysis plant at Baltimore has experienced problems with refractory failure, due to repeated stoppage for repairs to other parts of the plant, so this can be a significant problem.

No consideration has yet been given to the importance of any but pure economic factors in deciding on the amount of refuse to be dealt with by a plant. There is at least one other point which must be considered, namely labour relations. At the West Midlands incinerator plants, bonus schemes are in operation, and the bonus paid to workers at each plant depends on, amongst other factors, the amount of waste processed at that plant. The scheme was negotiated with the assumption that the plants would be used as fully

as possible - this was then the policy of the County Council. If this policy were to be changed, it is likely that the scheme would have to be renegotiated in order to maintain good labour relations. The effect of such negotiations on the cost of labour at the plants obviously cannot be predicted, but it must be expected that no reduction in the average level of earnings would be accepted. Thus no savings can be anticipated unless some workers are made redundant (and, as noted previously, this would only be practicable if a change in the operation, by reducing the number of shifts or streams worked, were to be made). Because of these considerations, and the policy of the Council referred to above to make full use of incineration capacity, it was assumed for most of this work that plants would always be used to their full capacity. With this assumption, the costs of the plants are constant and need not be considered when planning the waste management strategy (though of course they will be required for financial planning, this need not be done so far in advance, nor is it necessary to analyse the costs in such detail).

The "capacity" of plants has been referred to several times, and the meaning of this term must now be discussed. When a plant is designed, it is rated in terms of the amount of refuse it will handle; normally the figure is quoted in tonnes per hour. This indicates the throughput possible over a short period, of perhaps a few hours, without major mishaps. In practice, this rate cannot be sustained for longer periods, due to breakdowns, start-up and shut-down intervals, etc. Over a longer period still, changes in the nature of refuse, particularly its density, will affect plant capacities. The separation-incineration plants would

be expected to have a lower capacity with present refuse than for the design date, since the initial screening operation no longer removes very much fine dust, nor are the picking belts in operation. In fact, these plants, in the West Midlands at least, are still approaching the expected levels; this is attributed to conservative design, which allows for such variations by providing a wide safety margin in the specifications. This draws attention to another point; the specifications cannot be assumed to give an accurate indication of the actual capabilities of a plant. Variations in design mean that it is not possible to predict which of the stages of processing will be the limiting factor on throughput, let alone what the limit will be, for long-term operation. The only realistic procedure for existing plants is thus to use records of the actual performance of the plants over a long period (a year is probably not long enough). In the West Midlands, "budget" figures, based on experience, are used for the day-to-day capacity of a plant; for annual capacities, estimates are made, based on knowledge of the conditions limiting throughput at each plant as well as its performance in the past. These figures are influenced to some extent by the shortages of refuse experienced at a plant, but this seems to be inevitable - there is really no way to determine the possible throughput of a plant under conditions which have never occurred in practice, such as a perfect match between input and capacity. Since the actual throughput in any one year is likely to diverge somewhat from the expected figure in any case, this is not a serious limitation, but it must be remembered that, for incinerators at least, the capacity cannot be regarded as a hard-and-fast figure.

TABLE 5.7 ANNUAL PROCESSING CAPACITY OF INCINERATOR PLANTS

All figures in tonnes per annum

PLANT	ACTUAL	PROBABLE	BUDGET
Perry Barr	77483	85000	119600
Wolverhampton	72373	73000	102960
Dudley	46249	47000	70200
Sutton C.	16667	17000	18720
Coventry	76205	100000	167960
Castle Brom.	52222	53000	60320
Lifford	48943	49000	53040
Tyseley (new)	-	100000	150000

Table 5.7 shows the capacities of the incinerator plants expected to be operating in the West Midlands in 1978, on three different bases. "Actual" figures are the quantities burnt during the financial year 1976-7, and "probable" figures are the quantities predicted (subjectively) to be burnt in 1978, allowing for all the considerations outlined above. "Budget" quantities are those which would be burnt if the plant operated for 52 weeks per year at the weekly budgeted rate, and thus indicate in terms of annual figures the throughput that can be expected under good conditions. Obviously the figures for the new Tyseley works, which is not yet in operation, are rather speculative, and are likely to be less accurate than the others.

Most of the discussion above is essentially concerned with incineration plants rather than transfer stations (the only other intermediate plant used in West Midlands). The Rotton Park St. transfer station has a capacity of about

50000 tonnes per annum, and has proved sufficiently reliable to achieve this throughput regularly. The problems with bonus schemes, etc., discussed above, have also not occurred at this plant, so the above figure can be regarded as a reliable throughput which need not be fully utilised unless required.

One processing plant (in a sense) which is not dealt with above is the IMI refuse derived fuel scheme. The throughput here is not under the control of the County Council, and the project has not been running for long enough to establish a definite rate. However, the agreement allows for the Council to provide up to 38100 tonnes of refuse per annum, and since the project seems to be operating successfully, it is likely that the full amount will be required in the near future. This figure has therefore been assumed.

In order to assess the cost of disposing of the residue from the plants, it is useful to know the proportion of the weight of the input refuse which is produced as residue. This information, derived from the plant returns for the financial year 1976-7, is shown in table 5.8. It will be seen that there is little difference between the different plants; there is some variation in the figure for an individual plant, depending on the input refuse composition and the manner of operation. The average figure of 33.5% has therefore been assumed for all incinerators. The table also shows the percentage of ferrous metals recovered from the refuse, and the resultant income per tonne of input refuse - this can be subtracted from the "cost proportional to throughput" shown in table 5.6. The price obtained

depends on whether the metal is extracted from the crude refuse or the incinerator residue; these two forms are known as "bright scrap" and "black scrap" respectively, and in 1976-7 the prices received for them (baled) were £18.10 per tonne and £17.69 per tonne respectively. The variation in the proportion extracted at the different works is considerable; this is probably mainly due to variations in the efficiency of the magnetic separation, though there may also be some differences in the proportion of ferrous metals in the input refuse.

TABLE 5.8 INCINERATOR PLANT RESIDUES AND FERROUS METAL RECOVERY

PLANT	WASTE INPUT (tonnes)	RESIDUES (ASH AND SCREENINGS)		METALS RECOVERED		
		(tonnes)	(% of input)	(tonnes)	(% of input)	(p/t)
Perry Barr	77483	22134	29	2437	3.1	55
Wolverhampton	72373	26618	37	1254	1.7	30
Dudley	46249	17820	39	-	-	-
Sutton C.	16667	5887	35	803	4.8	85
Coventry	76205	27021	35	3998	5.2	92
Castle Brom.	52222	15318	29	2036	3.9	71
Lifford	48943	17323	35	2436	5.0	90

5.4 Models of Future Treatment Plants

In preparing a long-term plan for waste management, it is obviously necessary to consider the possibility of introducing some new facilities for the treatment of waste, and one of the major factors in deciding whether or not to do so will be the anticipated costs of the schemes considered. It is therefore necessary to make some estimates of the likely costs of plants which do not yet exist; with a number

of innovatory systems, such as pyrolysis, entering the field, costings may even be required for a type of plant which does not exist on this scale anywhere. In view of the difficulties, discussed above, in assessing the costs of plants which do exist, it must be expected that this task poses considerable problems.

With a type of plant, such as the direct incinerator, of which a substantial number already exist, both in this country and abroad, it might be thought that the costs of any projected plant would be easy to estimate. However, there are a number of aspects of design which vary considerably from one plant to the next, with the result that simply specifying, say, a direct incinerator of such-and-such a capacity does not determine the cost of the plant. One major factor which varies considerably is the standard of appearance and construction of the buildings to house the plant, which range from simple steel-frame structures to substantial brick buildings screened by trees and landscaped. The working conditions in the plant may also vary, though recent plants are usually better in this respect, with the provision of more mechanical aids for (e.g.) baling ferrous metals, more efficient dust extraction equipment, and so on. Another factor is the provision of various ancillary features, such as shears for large single objects, separate incinerator units for destroying animal carcasses, condemned meat, etc., and vehicle garaging and servicing facilities. There is a tendency for the larger installations to include more of these "optional extras"; together with the tendency to use several streams

in larger capacity plants, rather than one large grate, this means that the economies of scale which might be expected in plants of this nature are not apparent in practice. (There are, however, benefits of other sorts in the larger plants, which should not be forgotten). These points are illustrated by the comparative study of six direct incineration plants, including those at Perry Barr and Sutton Coldfield, which was carried out for the Department of the Environment (Atkins (1974)). Some figures from this source are shown in table 5.9 which indicates the extent of the variations found in practice; much of the variation in costs per actual tonne can be attributed to the differences in utilisation of the different plants. Note that the throughput quoted for the Sutton Coldfield plant is a nominal figure quoted in the report as likely in a normal year, this being necessary because the actual figure was considered unrepresentative, unlike those for the other plants.

This example shows that accurate estimates for the costs of a proposed plant will not be possible until detailed plans have been drawn up. Rough estimates, however, can be made, based on generalised conditions, to indicate whether a particular process is likely to be worth detailed study. A set of such figures, prepared for the initial report on the West Midlands waste disposal strategy (WMCC (1976a)) is shown in table 5.10. Note that income from the sale of salvaged materials or recovered heat is not allowed for in these figures. The costs are at late 1975 prices, and all assume that 120 000 tonnes per annum

TABLE 5.9 CAPITAL AND OPERATING COSTS OF SOME INCINERATOR PLANTS
(after Atkins (1974))

PLANT	DESIGN CAPACITY (tons/h)	CAPITAL COST (£-h/ton)	CONTRACT DATE	ACTUAL THROUGHPUT (tonnes/a)	DEBT CHARGES (£/t)	OTHER COSTS (£/t)
Bolton	16	39400	3/69	33420	2.21	1.64
Exeter	8½	65900	3/68	22336	2.70	2.93
Sutton C.	10*	38300 †	7/67	20000 ‡	2.36	4.82
Derby	15	57400	9/67	62981	1.58	1.61
Glasgow	24	87300	6/67	109552	1.60	2.06
Perry Barr	24	72300	11/67	80874	1.39	2.45

* tonnes/h

† £-h/tonne

‡ estimated

TABLE 5.10 COMPARISON OF COSTS OF VARIOUS METHODS OF DISPOSAL
Based on 120 000t/a

PROCESS	DEBT CHARGE (£/t)	TOTAL COST (£/t)	LANDFILL REQUIREMENT ₃ (thousand m ³ /a)
Landfill	0.05	0.92	300
Transfer, no salvage	1.19	2.41	300
Transfer, ferrous salvage	1.38	2.71	260
Rail transfer and landfill	1.63	8.11	(300)
Pulverise, ferrous salvage	1.75	3.40	180
High-density bale	3.13	4.70	120
Direct incinerate	6.88	9.31	42
Direct incinerate, heat used	8.75	11.65	42

are dealt with. The landfill volume required is estimated for each process, as one indication of the advantages of more expensive methods (note that no allowance is made for the need to divert refuse to landfill if breakdowns occur in processing plant). In the original, the cost of transport and final disposal is included for each system, but these have been omitted here because transport is dealt with separately. However, for making a first judgement as to the merits of different systems, it is important to bear in mind the reduction in transport costs, as well as final landfill volume requirement, obtained by such processes as high-density baling. Also, the omission of this cost makes rail transfer to a distant disposal site seem less attractive financially than it is in fact, because the cost here includes that of the train, and landfill at the destination. (The landfill requirement is indicated in brackets for rail transfer because it is required at a considerable distance from the source of the refuse, and the volume is readily available for this type of operation).

One of the points brought out in the Atkins study (op.cit.) is that the decision on the size of a planned plant appeared to be made in a very haphazard way, resulting in the very wide variations found in the level of plant utilisation. This is certainly a difficult problem, especially when considering the construction of a new plant in an area already containing a number of such facilities. The catchment area of the plant must be decided upon, taking into account the requirements of the existing plant. Other factors in this decision are possible economies of scale in constructing a larger plant, and the opposing

tendency to increasing costs of transport as the catchment area is extended. Wilson (1978c) shows how the optimum (in the sense of cheapest) size of plant can be estimated, taking into account the two later factors and making some simple assumptions as to the distribution of arisings, etc., but this approach does not allow for the interaction with other disposal facilities, or the need to deal with all the waste arisings - it is perhaps more appropriate for use in the private sector, where such constraints do not normally apply, though it can give some indication of the magnitude of the transport cost effect on the economy of scale. This reference concludes that, for plausible economies of scale in processing costs alone, the total cost (including transport) is fairly insensitive to plant size, so that other factors must be considered in making a decision.

In order to reach a decision in practice, it is thus necessary to consider the whole system being dealt with, as discussed in chapter 6. Some allowance must now be made for the capital cost of constructing a new plant, unlike the case of an existing installation. The simplest approach is to assume a constant capital cost per tonne, which can be added to the operating cost, with no constraints on the throughput of the plant. This can give misleading results, since variations from one time period to another in the throughput of a plant will result in corresponding variation in the assumed capital cost; also, if discounting is used (see section 5.6), the capital costs will not be properly dealt with. It is likely that some idea as to a suitable size for the plant will exist already in the mind

of the planner, so this may be used as a guide to restrict the range of throughputs to be allowed. This also makes the assumption of constant capital cost per tonne (i.e. no plant economies of scale) more plausible. Ideally, the cost should be related to the maximum annual throughput assigned to the plant in any time period, but no algorithm is known which would allow such a cost to be imposed in the computation. On the other hand, the imposition of rigid constraints on the throughput of a plant could reinforce the planner's preconceptions, even when these are incorrect. The most effective approach in practice seems likely to be the investigation of several different sizes of plant, for each of which the throughput is restricted to within a reasonable range. By experimenting with different sizes in this way, it is possible to narrow down the possibilities in stages until a close approximation to the conceptual "optimal size" is found. This approach is much closer to the procedure for existing plants, and when using it, the capital costs of new plants should not be included in the unit cost used for calculation - rather the appropriate sum should be added to the total cost found at the end of the calculation, and only the "variable costs" discussed in the last section should be included in the unit cost.

5.5 Models of Landfill

As with the other activities discussed in this chapter, landfill operation will only be considered in relation to the strategic planning problem. The use of mathematical models has been proposed for site management in the operational sense (e.g. Christensen and Haddix (1974)), but this is outside the scope of this research. This section

will discuss the location of potential sites, and their assessment as to technical suitability and cost.

The first problem to be dealt with is the location of potential sites. In some areas, where extensive mineral extraction has taken place, this may not be a problem; it is also possible that sites already in use provide sufficient volume for the foreseeable future. However, in conurbations like the West Midlands County, neither of these cases applies, and there is an urgent need to locate new sites. If sites within the conurbation are sought, there are serious problems in locating them by conventional survey techniques, since they are likely to be invisible from roads or other public places. Under these conditions, the use of aerial photography can be very valuable, enabling all voids which might be suitable to be located quickly and at less cost than a comparable ground survey (Ballam and Collins (1975)). Experienced interpreters of aerial photographs can also obtain most of the information required to determine whether the site will be technically suitable for landfill - for instance, the quality of access and proximity to houses - although the geology and hydrogeology cannot usually be observed in sufficient detail. An important factor which cannot be ascertained in this way, however, is the ownership of the site. Experience in the West Midlands shows that many apparently disused mineral workings are still owned by the mineral extractors, who are awaiting an improvement in the market price before continuing with the operation of the site. Even when a site is worked out completely, the owners may be unwilling to make it available to the local authorities, since it will be valuable for the disposal

industrial wastes (perhaps produced by a company related to the mineral extraction firm). In areas where there is a shortage of landfill sites, it is therefore to be expected that difficult negotiations will have to be undertaken to obtain the use of suitable sites.

The suitability of a site for landfill purposes is a complex question. The aspect currently receiving most attention is that of the possible pollution of groundwater by leachate from the deposited refuse (see section 1.5), and in order to deal with this possibility it may be necessary to conduct an investigation into the local hydrogeology. With the introduction of the new site licensing procedure under the Control of Pollution Act 1974, consultations with the appropriate water authority will be required as a safeguard in this respect. In other respects, however, such as proximity to houses, it is likely that the disadvantages of a site will be weighed against its advantages compared to possible alternatives. If a site in an urban area is required, it will almost certainly be closer to housing than if one outside the area were to be used; on the other hand, a more distant site will require longer transport of refuse, which causes some loss of amenity to those living along the roads used, as well as increased costs. Thus no firm rules can be laid down as to what will be acceptable.

Depending on the nature of the site, different amounts of preparatory work will be required at different sites, and in some cases this may be very expensive - for instance, if sealing and provision of drains is necessary to avoid possible pollution of groundwater. Thus, as in the case of treatment plants (perhaps even to a greater extent) it

is not particularly useful to quote generalised costs; rather, detailed study is needed of potential sites in order to select those which will be most economic. With landfill sites there is an additional factor which does not come into consideration when planning treatment plants, namely the cost of buying or leasing the site. (Obviously plants do require sites, but this is normally a minor factor in their cost, and the requirements of the site are not specialised, unlike those for a landfill site). It is increasingly common for the owner of a worked-out quarry or similar void to recognise its potential value for waste disposal, especially in areas where such sites are in short supply, and lengthy negotiations are likely to be needed to agree on prices and conditions of use for new landfill sites.

Although these factors make it difficult to predict the initial cost of a landfill site until agreement has been reached (by which time any analysis of the decision to acquire the site comes too late), it may be helpful in the course of negotiation to have some indication of the value of the site in the operation of the county waste management system. For this purpose, it is not necessary to know what the initial cost of the site will be; so long as its location and potential volume are known, modelling the system both with and without this site will indicate its effect on operational costs, and give some indication of how much it would be worth paying for this site. Of course, such results would depend on assumptions about the availability of other sites in the county; if a site is urgently needed and no others are considered in the

model, it will inevitably be found that this site is enormously valuable. This is another argument in favour of considering the whole waste management system in a model - examples of the use of such a model are given in the next chapter.

Unlike treatment plants, landfill sites provide a disposal facility whose total capacity is limited; it therefore makes sense to talk about the initial cost in terms of pence per cubic metre, or (assuming some definite density of deposited material) pence per tonne. Indeed, if the site is leased rather than purchased, payments may well be made according to the amount deposited. Thus for existing landfill sites, it makes sense to include the cost of acquisition, as a cost per unit volume, in the cost of running the site.

The actual running costs of a site, apart from its acquisition, are quite low compared to those of a treatment plant, but like those of a plant, they do not vary proportionately to the amount handled. The main cost is that of the tractor and driver (and any other employees on the site), and these will be needed as long as the site is open, whether or not waste is being delivered at that minute. As for plants, a large change in the amount handled could result in a need for more (or fewer) employees, and perhaps a larger type of tractor, or two machines instead of one, but for relatively small changes there will be virtually no change in the cost of operation. In this study, therefore, the only cost considered for landfill sites is that of acquisition, so long as a given system of facilities is being modelled. However, when comparing

one system with another, some figures for the actual operational cost are needed. The sum budgeted for the operation of existing landfill sites in 1976-7 was £300 440. Approximately a million cubic metres of space were used, so this could be described as a cost of about 30p/m³; however, on the arguments used above, it is probably more useful to say that eight sites for crude refuse, and one for incinerator residue only, were in use, so that the cost is £33 380 per site per annum approximately. The cost for individual sites will clearly depend on the sophistication of the operation to some extent, for instance on the type of tractor used, but it is not possible to obtain figures on the costs of individual existing landfill sites in the West Midlands.

As noted above, in order to relate the volume of a site, determined by survey, to the weight of material which can be deposited there, it is necessary to assume some relationship between weight and volume in the final deposit. The figure currently assumed within WMCC for crude refuse, including the necessary cover of inert material, is 2.5 m³/tonne. This is a high figure by comparison with other sources, and is to some extent deliberately conservative, to allow for possible future trends towards lower refuse density. However, the way in which the site is operated makes a significant difference to the final density of the waste. In particular, the type of tractor used is known to be important, and the use of the special heavy steel-wheeled units recently developed specifically for use on landfill sites has been found to reduce the volume of a tonne of refuse, with cover, to as little as 0.75 m³ (Briggs (1976), Bratley (1976)).

For incinerator residues, and non-combustible trade and civic amenities wastes, which are necessarily dealt with at landfill sites, a figure of $1 \text{ m}^3/\text{t}$ is used by WMCC for those which are not required for covering refuse or providing tip roads, etc. The figures used by WMCC have been assumed for most of this study.

The actual cost of acquiring landfill space has not yet been discussed. In most cases, the sites currently in use have been used for some years by the existing local authorities, and their cost is either unknown or so out of date as to be of little value as an indicator of current costs. However, the most recently acquired site used by WMCC cost $21.5 \text{ p}/\text{yd}^3$ ($28.1 \text{ p}/\text{m}^3$) in an agreement completed in November 1975. This price includes basic site preparation but not such features as the provision of a weighbridge. Allowing for inflation, a present cost of about $35 \text{ p}/\text{m}^3$ could be expected for a comparable site. However, the scarcity of such sites is likely to result in their prices rising faster than the general level of inflation. It is estimated that about a million cubic metres of various minerals are extracted from sites in the West Midlands annually; since this amount of space is required by the County Council alone, without considering the needs of industry and private waste disposal contractors, it is clear that landfill sites will become increasingly rare within the West Midlands County. The effects of this can be explored using the models described in the next chapter. For present purposes, it will be assumed that landfill space can be valued at $35 \text{ p}/\text{m}^3$, or (assuming $2.5 \text{ m}^3/\text{t}$) $87.5 \text{ p}/\text{t}$ for crude refuse.

The County Council makes use of one privately operated landfill site, at Packington in Warwickshire. This is part of a large complex of potential sites, whose total capacity is not known, which is used by a number of other organisations as well as local authorities. There is an agreement, renewed annually, on the scale of charges for the use of the site - there is a price per tonne which falls as the amount delivered increases. From the viewpoint of the County Council, this site resembles a treatment plant more than a landfill site, in that it is the rate of delivery rather than the total volume delivered that is of interest - the total volume of the sites available is very large, so the possibility of filling them within the period of the Waste Disposal Plan has been neglected, although with the advent of the site licensing procedure under the Control of Pollution Act 1974, it is possible that not all the existing space will be licensed for this purpose. In this work, it has been assumed that up to 50 000 tonnes of waste per annum will be accepted indefinitely, and the current cost has been taken as £1.50 per tonne (this is approximately the current cost, though because of the sliding scale of charges it is not possible to give an exact figure which would apply under all conditions).

For the sites used exclusively by the County Council, it is necessary to estimate the volume available at the start of the planning period. To determine the volume available at a site, a survey is needed to find the current contours, and a plan of the final contours must be made;

the volume between these two surfaces, allowing for final cover and any other space required for other materials than refuse and its primary cover, is the volume of the site. In practice, since surveying a site is a fairly lengthy and skilled operation, it is carried out only occasionally (perhaps once a year), and in between these times the current contours, or the volume used since the last survey, can only be estimated. Also, most landfill sites receive substantial quantities of inert materials, from traders and civic amenities deliveries, which occupy a significant fraction of the site. Table 5.11 shows the proportions of inert material and refuse dealt with in each district of the West Midlands by landfill. Table 5.12 shows the current volumes of the landfill sites expected to be in use in the West Midlands in 1978, or to come into use later (some of the latter are still under negotiation), the volumes which they are assumed to provide at present, and the volumes expected to be used for crude refuse. The last figure is obtained by assuming that the relative proportions of refuse and inert materials in each district will remain the same as at present. Volumes are very dependent on the final levels assumed, and further extraction from some sites. Some future sites may not be used exclusively by WMCC, and this makes the volumes assumed even more indefinite.

5.6 Time Preference and Discounting

When planning for a fairly long period, such as ten years, it is essential to consider preferences as to how the effects, and in particular the costs, of activities

TABLE 5.11 LANDFILL SPACE USED FOR INERT MATERIALS AND REFUSE

All volumes in m³; figures for financial year 1976-7.

DISTRICT	VOLUME USED FOR:		REFUSE AS % OF TOTAL
	REFUSE, ETC.	INERT WASTE	
Birmingham	96500	11800	82
Coventry	40300	2300	95
Dudley	52000	50000	51
Sandwell	110000	45000	71
Solihull	162500	60000	73
Walsall	137500	90000	61
Wolverhampton	12800	4000	76

TABLE 5.12 VOLUMES AVAILABLE IN LANDFILL SITES

SITE	DISTRICT	TOTAL VOLUME (m ³)	VOLUME FOR REFUSE (m ³)	WEIGHT OF REFUSE (t)
Now in use or soon available:				
Bentley Lane	Walsall	150000	91500	36600
Mucklows Hill	Dudley	138000	70400	28200
Speedwell Road	Birmingham	120000	98500	39400
Blue Rock Quarry	Sandwell	245000	245000*	98000
Hay Lane	Solihull	150000	109500	43800
Barnfield Road	Sandwell	70000	49700	19900
Possible in the future:				
Booths Lane	Birmingham	1000000	820000	328000
Allsopps Quarry	Sandwell	1600000	1137000	455000
Birch Coppice	Walsall	380000	232000	92800
Tividale	Sandwell	1250000	888000	355000

* To be used for refuse only

should be distributed through time. At first sight it might appear natural to say that it is unimportant whether an expense is incurred now or in a few years' time. However, the possibility exists (in principle) of investing a smaller sum now, which with interest will be worth the required amount later. This is the basic argument in favour of using a "discount rate" to reduce costs to be incurred in the future to their present value, which is the sum which would have to be invested now in order to meet them when they arise. In local government, it is perhaps more realistic to consider the possibility of spending the sum now on some project providing immediate benefit, which would otherwise be postponed; rather than the interest rate on investment, the relevant discount rate then depends on social preferences as to the provision of the benefits in question now rather than later. Some writers have argued that the discounting approach is unfair to future generations, since by regarding costs in the future as less important than those in the present, it inevitably leads to systems whose cost increases with time; this can be justified on the assumption that economic growth will always occur, since this means that future generations will be better off than the present one, but this is not a universally accepted assumption. The aim of using these methods in local government is to provide a comparison between different possible uses of capital, and in order to provide a "fair" comparison, the discount rate normally used is determined by central government and known as the "Treasury test discount rate" - it is currently 10% per annum. However, Hawkins and Pearce (1971) point out that comparisons

on the basis of net present value, whatever the discount rate used, do not necessarily give fair results in a situation where the supply of capital is limited. In such circumstances, mathematical programming should be used to allocate the available finances between the competing projects. With the complex projects undertaken in local government, such an approach seems unlikely to be practicable. It seems, therefore, that the use of net present values with the Treasury discount rate, or some other arbitrary figure, will be unavoidable.

In the present research, the costs considered are in fact mainly operational rather than capital. However, the same principles are applied, and the use of discounting to a net present value is recommended by the Department of the Environment (DoE (1976a)). Despite the theoretical objections, therefore, a discount rate of 10% has generally been used in this work.

One other factor which must be considered in planning long-term expenditure is the possibility that different items may change in price relative to one another, i.e. that the rate of inflation may be different for different goods and services. For instance, it is possible that the increasing scarcity of petroleum will cause a rise in the price of road transport, relative to other activities; the availability of North Sea oil in Britain, however, will probably prevent this having a major impact for the next ten years at least. The scarcity of suitable sites for landfill in urban areas, noted above, will probably have some effect within this time; the likely magnitude of such an effect is hard to predict, but it is worth considering the impact that such changes would have on the

waste management plans being prepared, and an attempt to do this will be described in the next chapter. No consideration has been given to the effect of the general level of inflation; it can be argued that inflation should lead one to make investments sooner rather than later, so reducing the effect of the discount rate, but it will be assumed that such considerations are taken into account in setting the test discount rate. Thus the costs quoted in the next chapter will be net present values at current prices (unless otherwise stated).

The discount rate operates like compound, rather than simple, interest, so that the net present value of a sum x_n spent (or received) n years in the future is

$$x_0 = \frac{x_n}{(1 + r/100)^n} \quad .$$

where r is the annual percentage discount rate. If the discounting is considered to be continuous, so that n need not be integral (as is necessary for costs incurred continuously, i.e. operational rather than capital costs), then if the annual cost is c , the discounted cost for a small time interval δt at time t is

$$\delta c = \frac{c \delta t}{(1 + r/100)^t}$$

and the total discounted cost for the interval from t_1 to t_2 is

$$\begin{aligned}
 C &= \int_{t_1}^{t_2} \frac{c \, dt}{(1 + r/100)^t} \\
 &= \frac{c}{\ln(1 + r/100)} \left[(1+r/100)^{-t_1} - (1+r/100)^{-t_2} \right] \\
 &= c \tau \left[\exp(-t_1/\tau) - \exp(-t_2/\tau) \right] ,
 \end{aligned}$$

$$\text{where } \tau = \frac{1}{\ln(1 + r/100)} .$$

This is the form required for discounting the operational costs during a time period, as in the calculations described in the following chapter.

The programs described in the following chapter allow for growth rates in the various costs considered, as well as an overall discount rate, to be included. The growth rates are assumed to be exponential, like the discount rate. Allowing for a growth rate of r_g per cent, and a discount rate of r_d per cent, the total discounted cost for the period from t_1 to t_2 can be shown, analogously to the last derivation, to be

$$C = c \tau \left[\exp(t_2/\tau) - \exp(t_1/\tau) \right] ,$$

where

$$\tau = \frac{1}{\ln(1 + r_g/100) - \ln(1 + r_d/100)} .$$

This formula is implemented by subroutine GROWTH in the computer program (Appendix C).

6. OVERALL DECISION MODELS

Having discussed models of waste production and of individual activities in waste management, the modelling of the overall decision problem for a county waste management strategy will now be considered. It is rather surprising to find that this area has received more attention in the past than the models of individual activities, which seem to be more basic. This is perhaps because previous work has mostly been carried out away from the actual problem situation, and has been more concerned with conceptual development than implementation. Conceptually, the models of individual activities can be regarded as subsidiary to the overall model, and of course the form of the overall model must influence them, since it demands information in a particular form. In an actual application, however, the parts must be analysed first, and it is the availability of data at this stage which limits the power of the final model.

It is important to consider the overall model, rather than limiting the view to one aspect at a time, because there are significant interactions between the various components of a waste management system. Thus, for instance, landfill in general is cheaper than incineration; but if an incinerator can be built in the centre of the collection area, while the only usable landfill sites are many miles away, the economics may reverse. In such a simple case, allowance can be made for the cost of

transport when assessing the options, but when considering changes in an existing system, the cost of transport cannot be calculated without deciding which collection areas will be assigned to the new facilities, and this decision must take into account the effect on existing arrangements. Thus it is the transport of waste that is the central problem in overall planning; since transport costs are a substantial part of the total cost of the system, the effect on total cost of the interaction of transport arrangements must be taken into account in order to obtain a realistic estimate of the cost of any proposals.

One aspect of the interaction between facilities is concerned with the sequence in which landfill capacity at different sites is used. When there are a number of alternative sites available, it will generally not be desirable to operate them all at once; rather some will be used until they are full, and then the waste flow will be transferred to others. If the decision model is to represent this sort of consideration, it must clearly incorporate explicitly the possibility of changes over time. This feature is also needed if the model is to deal with the possibility of constructing treatment plants in the future, or indeed if such plants are already under construction but will not be completed for some time (as was the case in the West Midlands at the start of this study). It is therefore desirable that the overall decision model should be dynamic in this sense; static models of a single time period can give some idea of the best way to use facilities under the circumstances prevailing, but cannot optimise the use of landfill space

over time. The models used in this work have all been dynamic with time, but a number of authors have used static models in this area (for a review of overall models for waste management, see Wilson (1977b)).

Another consideration in constructing the overall model is to decide exactly what is to be aimed at in the use of the model - which decisions are to be incorporated into the model's operation and which are to be made by the user on the basis of information supplied by the model. The minimal assumption would seem to be that, given a system of facilities, the transport arrangements giving the minimum cost are to be found. This includes no consideration of the cost of the facilities themselves; the input to each may be fixed at the appropriate capacity or allowed to vary freely. This was the first form of model used in the present work, and the model and its use were described in a report written for the West Midlands County Council, whose text is included as Appendix B. A more formal description of this model and a later development of it will be given in section 6.1, and a rather more realistic version based on the same approach will be described in section 6.2. The results produced will be discussed in section 6.3.

A number of authors have used models in which the facilities to be used are selected from among those possible in such a way that the total cost of transport and operation is a minimum (e.g. Shields (1972); Skelly (1968); see Wilson (1977b) for a review). These models generally include the capital costs of facilities as a

fixed charge if the facility is used, and thus involve mixed integer programming. The choice of facilities is made solely on the basis of cost. In this study, it was considered that while transport arrangements could reasonably be chosen simply to give minimum cost, this would not be acceptable for disposal systems, whose impact in other ways might vary widely (whereas with transport, in general, lower costs would imply lower impact, this is not true when comparing alternative technologies for disposal). Such an approach has therefore been avoided.

Another possibility is to use a model to determine the optimum location(s) for disposal site(s), and then find practical sites as close as possible to these points. This approach places rather severe restrictions on other aspects of the model, and in a mainly urban area like the West Midlands, would seem to be rather unrealistic in any case. This approach was thus also not attempted in the present work. It has been used, for example, in some studies by the Local Government Operational Research Unit (Parker and Portlock (1974)).

There are, however, some other techniques which seem to offer advantages for the type of problem tackled here, but have not been used in this area. These include ways of dealing with multiple objectives, and with uncertainties in the data. Section 6.4 will discuss these possible improvements to the overall model.

6.1 Transshipment Model Optimising over Time

The first model developed for the overall decision problem was basically a transshipment problem (Orden (1956))

with capacity restrictions on the flows. The assumptions in this model are:

- Landfill sites and incinerator plants are treated as final disposal points;
- A landfill site has a specified total capacity, which may be used at any rate during the lifetime of the site;
- An incinerator has a specified maximum annual input;
- Transfer stations may exist, which have specified maximum annual throughputs, and a specified unit cost in each time interval;
- All facilities (landfill sites, incinerators and transfer stations) may open at the beginning of the planning period or any later time, and close at any time after they open;
- A landfill site which is required to close within the planning period must be filled by that time;
- The quantities of refuse arising at various points are specified for each time interval, and these quantities must be dealt with;
- The cost per unit weight of transport from collection, and from transfer stations if used, is specified for each time interval;
- There is no cost saving if incinerators are not used to their full capacity, nor any value attached to unused landfill space at the end of the planning period;
- The objective is to minimise the overall cost of the operation, regardless of the cost to individual collection authorities.

In the use of this model, the assumption that no saving was made by underusing incineration capacity was not usually effective, since it was normally assumed that incinerators must be used to their full capacities. This was mainly for reasons of labour relations - bonuses are paid to the plant staff which depend on throughput, and deliberate reduction of the throughput would obviously not be accepted without renegotiation of the basis of the bonus scheme (which would make it impossible to predict the savings made, if any).

The problem being dealt with is essentially that of finding a minimum-cost flow in a network, which was discussed in section 3.5. There is an added complication in the need to deal with changes in the network over time. As argued above, the system could be treated separately in each time period, were it not for the need to optimise the way in which landfill resources are used. This suggests the way in which the changes with time can be represented in the problem. The sources of waste, transfer stations and incinerator plants are represented separately for each time period, and interlinked in sub-networks for each time period; the separate sub-networks are connected to nodes representing the landfill sites (which are not replicated for each time period). A simple example of such a multi-period network is shown in Figure 6.1.

The minimum-cost flow problem for the multi-period network may be formulated as follows:

$$\begin{aligned} \text{Minimise } & \sum_{ijt} c_{ijt} x_{ijt} + \sum_{ikt} c_{ikt} x_{ikt} + \sum_{ilt} c_{ilt} x_{ilt} \\ & + \sum_{jkt} c_{jkt} x_{jkt} + \sum_{jlt} c_{jlt} x_{jlt} \end{aligned}$$

subject to

$$\begin{aligned}
 \text{(a)} \quad & \sum_j x_{ij t} + \sum_k x_{ikt} + \sum_l x_{ilt} = a_{it} && \text{for all } i, t; \\
 \text{(b)} \quad & \sum_i x_{ij t} - \sum_k x_{jkt} - \sum_l x_{jlt} = 0 && \text{for all } j, t; \\
 \text{(c)} \quad & \sum_i x_{ij t} < q_{jt} && \text{for all } j, t; \\
 \text{(d)} \quad & \sum_i x_{ikt} + \sum_j x_{jkt} < b_{kt} && \text{for all } k, t; \\
 \text{(e)} \quad & \sum_{i,t} x_{ilt} + \sum_{j,t} x_{jlt} < v_l && \text{for all } l;
 \end{aligned}$$

where i labels the collection centroids,

j the transfer stations,

k the incineration plants,

l the landfill sites,

and t the time periods;

$x_{ij t}$ (etc.) is the quantity flowing from i to j (etc.) in t ;

$c_{ij t}$ (etc.) is the unit cost of transport from i to j (etc.) in t ;

a_{it} is the quantity of refuse arising at i in t ;

q_{jt} is the capacity of transfer station j in period t ;

b_{kt} is the capacity of incinerator k in period t ;

and v_l is the capacity (in tonnes) of landfill site l .

All quantities are specified in tonnes, or pounds per tonne for costs.

The constraints may be interpreted as follows;

(a) the total amount removed from each collection centroid in each time period must equal the arisings there in that period;

(b) the input to each transfer station in each time period must be balanced by its output;

- (c) the input to each transfer station in each time period must not exceed the specified maximum;
- (d) the input to each incinerator in each time period must not exceed the specified maximum;
- (e) the total input to each landfill site must not exceed the specified capacity.

The capacity limits (c), (d) and (e) are written as inequalities, but if full use is required, the $<$ may be replaced by $=$. The plant capacities are required in tonnes per period, which is convenient since the periods may vary in length; in practice it is assumed that the annual capacity of each plant is constant, i.e.

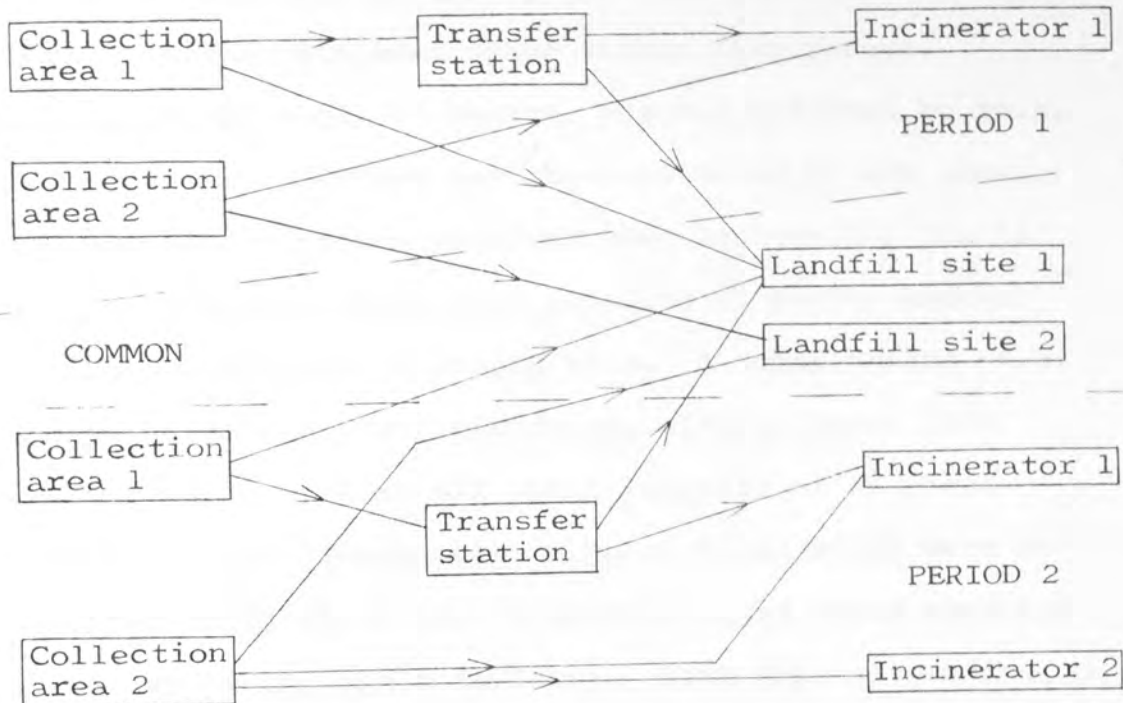
$$b_{kt} = B_k z_t$$

$$\text{and } q_{jt} = Q_j z_t,$$

where z_t is the length in years of time period t , and B_k , Q_j are the annual capacities.

The distinction between landfill and incineration disposal has here appeared in the formal statement of the problem for the first time. It is convenient to make this distinction, although it is formally unnecessary at this stage, in order to clarify the way in which the multi-period network can be treated as an ordinary network problem. Later developments in the model will require different constraints to be imposed on the different sorts of point in the network, so it will ultimately be unavoidable in any case.

FIGURE 6.1 SIMPLE EXAMPLE OF A MULTI-PERIOD NETWORK



It can be seen that the problem has the form of a transshipment problem (section 3.5), even in this multi-period form, except for constraint (c) - the way in which this was dealt with is explained below. The first approach to it was made using the program for the transshipment problem supplied by International Computers Ltd. (ICL), the manufacturers of the University's computer (International Computers Ltd. (1968)). In applying this program to the transport of refuse, one technical point should be noted. The problem as formulated (section 3.5) allows a supply point to produce not more than its capacity, and a demand point to receive not less than its requirement. In the case of waste, it is required that a disposal point receive not more than its capacity, and all the waste arising must be collected. Thus in order to represent

the problem, the disposal sites must be treated as supply points and the collection centroids as demands. This may be interpreted as saying that the commodity being transported is disposal space rather than refuse. Transport costings, of course, are not affected by this, since two-way journeys must be considered in any case. However, since it was required that incinerator plants be provided with their full capacity of waste, another device was adopted to ensure this. A dummy demand (i.e. source of refuse) was introduced, with arisings just sufficient to take up all spare capacity at disposal sites; it was linked only to those sites which were not required to be fully used (landfill sites which need not be filled by any definite time). With this alteration, the problem becomes symmetric between supply and demand points, and formally it would be possible to represent arisings as supplies and disposal as demand. However, the original arrangement was retained, partly because the input format for the ICL program was such that it was more convenient, and partly because it was preferred conceptually. If we focus on the decisions being made, rather than the physical process of transport, this arrangement is closer to the original concept of the transportation and transshipment problems, where supply is under the control of the decision-maker in the longer term, whereas demand is not. This may again become significant when considering uncertainties in future demand.

The standard transshipment program incorporates capacity limits on transport links, which are not required in the current problem; however, it does not allow for costs or

limits on the capacity of transfer stations, which are required. This can be dealt with by representing each transfer station (in each time period) by two points rather than one in the network. These two points can be thought of as representing the input and output ends of the station; they are joined by an arc representing the plant itself, to which are attached the costs and limits.

For the purposes of the model, arisings were considered to be concentrated at 22 centroids (see section 5.1). Three transfer stations (only one of which exists at present), ten incinerators (including the IMI plant, and with a change in capacity at Tyseley to represent the opening of the new plant) and eleven landfill sites were considered, in a maximum of four time periods. Such problems required several minutes of mill time (on an ICL 1905E) for their solution.

In order to reduce the need to input large amounts of repetitive data for the multi-time-period model, a simple FORTRAN program was written to generate the data. This provided for a variable number of periods, of different lengths - arisings and disposal capacities were specified as annual figures, and the program calculated the correct figures for each time period. Provision was made for change of arisings with time, in the form of an annual (exponential) growth rate; the percentage growth could be specified to the program, which would then calculate the arisings for each time period on this basis. Rather than tabulating the transport cost for each possible trip, the time for the trip was tabulated, and the cost per unit time input to the program as a separate figure - this made

it easier to try out different cost figures. The program, consisting of about 200 lines of FORTRAN, took only a few seconds to run.

A number of runs were carried out using this system, with varying data. The most obvious problem with it was the form of the input and output. The transshipment package requires each point in the network to be given a name of up to six characters. When dealing with (for instance) Castle Bromwich incinerator, Castle Bromwich North and South collection districts, all in several time periods, it was difficult to produce short names which indicated the point referred to clearly, and in fact codes were used. This made the output rather difficult to interpret. With periods of varying lengths, further difficulty was caused by the fact that the quantities in the output were indicated in terms of the amount in a period, and some arithmetic was necessary to obtain annual flow rates and costs. It would have been possible to write another program to process the output into a more convenient form, and one more suitable for use directly by waste disposal personnel - the standard output is hard to read for anyone without some understanding of the mathematics. However, such a program would involve considerable character handling, which is difficult to arrange in FORTRAN, and would only be suitable for use with the ICL package, which was known to be obsolescent. Since algorithms for this type of problem have been published and are fairly straightforward, it was decided to produce a program to carry out the complete calculation, accepting

input and producing output in forms which would be convenient for the application.

The algorithm chosen for the program was the "out-of-kilter algorithm" of Ford and Fulkerson (1962). This is essentially the same algorithm as that used by the ICL package, but not all the features of the algorithm can be used effectively in the package. Two additional features which have been used in the new program are the imposition of lower, as well as upper, bounds on the flow along a given arc, and the possibility of starting the calculation with a flow system previously calculated for a similar network. The use of lower bounds means that it is unnecessary to introduce the dummy source of refuse previously used; a plant or landfill site can be required to be used to its full capacity, or any fraction (perhaps something like 90%), by imposing the appropriate lower bound on the relevant arcs. When calculating the costs of several related possible arrangements, starting each calculation with the flow system calculated for the preceding one saves a substantial amount of computer time, since the new solution will be very similar to the previous one (and the calculation is iterative, i.e. it improves the solution bit by bit until no further improvement is possible).

The algorithm works with a closed network, without sources or sinks, and considers flows circulating in it. In order to represent sources and sinks, it is only necessary to introduce one dummy node, from which all sources are supplied and to which all sinks return. The arcs to and from this node are given suitable lower and upper bounds to produce the requisite flows from the

sources and to the sinks. In other respects, the network used for calculation is identical to that previously described.

In the output of this program, collection rounds and disposal facilities can be identified by names of up to 32 characters, and flows are tabulated in such a way as to make the results easily understood. Appendix E shows a sample of the output. The costs are also tabulated comprehensively, showing the cost to each district separately in each period, as well as the cost direct to the county and the overall total. In the input, because of the need to specify the times for many trips from one point to another, four-character codes are used for the points - the use of the full names every time in this context would be very inconvenient. The program provides facilities for repeated optimisation of the flow system, with various facilities turned "on" or "off" (i.e. available or not), and can be used interactively. The time for the first optimisation is usually about 60 seconds (mill time), with subsequent ones being much quicker, usually only a few seconds unless the changes are quite drastic. The complete flow system is not normally output to a terminal when the program is used interactively, but a short summary of the costs can be obtained, and the complete flow can be produced on the lineprinter. The program also gives an indication of the part of the network which is infeasible, if infeasibility is found. When a flow network or cost summary is printed, a list of the facilities currently excluded from the network is given.

It is possible to include comments in the main data input, which are printed in the output; if several different sets of input data are used, this makes it possible to identify them. The original intention was that only one set of data would be established, and turning facilities on or off would provide sufficient scope for experimentation, but in practice it has been found useful to change the data for some purposes.

The program in this form was used for some time, with various data, and a report describing its operation was written for the West Midlands County Council. The text of this report is attached as Appendix B. The initial concern was with the use of transfer stations, of which two were proposed, and the program was used to evaluate the effect of building one or both of these on the transport costs, under a variety of assumptions as to the availability of landfill sites. It was found that the officers concerned preferred to have some qualitative indication of the flow systems being proposed, although it was recognised that these would not provide usable operational plans, in order to obtain some impression of the reasons for the use or non-use of particular facilities. For this purpose, many of the printed flow networks produced by the program were drawn out on maps to show the general trends of refuse movement. A possible enhancement to the program might be to provide such maps automatically, using the graph plotter; but because of the difficulty of dealing with overlapping networks of lines to produce a legible result, this has not been attempted in the present

work. Any such arrangement would need to be used with caution, to avoid the danger of over-reliance on the output of the program, to the extent of using the network flows as operational arrangements.

At a later stage, the possibility of closing some older incinerators, or reducing the quantity of refuse they dealt with, was discussed. In order to evaluate the effect this would have on operating costs, the operating costs of incineration and landfill had to be included in the calculation. The assumption was that unit costs could be used to represent the variable costs of these disposal methods (i.e. the costs which vary with input, rather than being already determined irrespective of the level of use of the facility). Provision had already been made in the program for a compound growth rate to be attached to each of the costs then included (transfer operation, collection vehicles and transfer vehicles); different rates could be used for the different components, to reflect (for instance) the possibility that the cost of the more labour-intensive activities would rise faster than general inflation in the future. This provision was extended to the incineration and landfill costs. Consequently a modification was necessary in the representation of landfill sites in the network; it was no longer adequate to represent them by a single node for all time periods, since this would make it impossible to attach different costs to the use of the site in different time periods. (The costs could have been attached to the transport of waste to the sites, but for reasons discussed

above it was desirable to distinguish transport and operation costs). Thus landfill sites are now represented by a set of nodes, one for each period, to which the transport arcs are attached; these are linked to a single node by arcs to which the costs for the appropriate period are attached. The single node is then linked as a sink to the dummy supply/demand point as before, by an arc whose capacity represents the total capacity of the landfill site in question. A listing of the program in its latest form is given in Appendix C, and the data for it, using the costs found in chapter 5, are shown in Appendix D. Appendix E shows the results from running the program using these data. A discussion of the results will be found in section 6.3.

In the early stages of using this program, the discounting facility was not in use. In these circumstances, there is no change in cost if a landfill is used in one period rather than another, so long as the total amount sent to it remains constant - in mathematical terms, there is a degeneracy between time periods. Consequently, it was often found that the flows generated involved wide fluctuations in the input to landfill sites with time. A site might be heavily used in one period, then unused for two more before coming back into use again. Such an arrangement is clearly uneconomic in reality, and in such cases manual adjustments were made to find a more realistic system (this proved quite easy, as the situation only arose where the same source could feed more than one landfill site, and the cheaper site could not accept all the arisings for the study period). When discounting is introduced, there is

a natural tendency to use the cheaper arrangements first, so the problem does not arise in this way.

A related point, however, is still relevant. This concerns the interpretation of the flow network in cases where the flow from a given source is allocated to more than one sink in a particular time period. Where the sinks are incinerators, or one is an incinerator and the other a landfill site, the arisings must be taken to be divided between them in the proportions indicated. If both are landfills, however, and a discount rate is in use, there is no reason to divide the flow; the result should be interpreted as indicating that one site is used for part of the period and the other for the remainder. Usually, the cheaper site will be used first, and often it will be found that this site is in use in the preceding time period, and the other is used in the following period.

This does, nevertheless, indicate one of the weak points of this approach - the absence of any consideration of setting-up costs at facilities, and a resulting tendency towards unacceptable fluctuations of input to them. The use of lower bounds on the input can control this to some extent, but manual examination and adjustment is probably necessary for best results. Another weakness of this model seems more serious, particularly for the West Midlands, where there are several incinerator plants in existence. The treatment of incinerators in this model neglects the need to dispose of the final residue, which in fact is deposited in landfill sites, some of which are also used for crude refuse; thus the rate of landfill use is underestimated by the model. The rationale given for this during development was that incinerator residue could

be used as cover, and could not therefore be regarded as occupying space that could otherwise have been used for crude refuse; also, some sites existed which could only accept residue, and it was thought that the lower water pollution risk and visual effect of depositing residue would mean that it would be fairly easy to obtain new sites for this purpose within the county. However, the shortage of landfill space has meant that efforts are being made to extend the use of "residue-only" sites to accept crude refuse; and the policy of accepting inert materials at landfill sites free of charge for use as cover has been found to result in the deposit of substantial quantities of such material, so that cover is not normally in short supply. Thus it seems desirable to include some consideration of the disposal of incinerator residue in the model. This requires a further extension of the model form, and it is no longer a network flow problem, but a more general form of linear programming.

6.2 Transshipment with Gains and Incinerator Breakdown

The residue from an incineration plant has roughly one-third the weight and one-tenth the volume of the input refuse. (The remainder of the weight is released to the atmosphere in gaseous form). The network flow problem cannot deal with situations where some definite proportion of the input to a node is lost (or gained), since the flow through this node is not conserved. However, the problem is still one of linear programming, and is known as the problem of transshipment with gains.

Having made this extension, another addition can also

reasonably be made. This is to include consideration of the problem of incinerator breakdown, which also leads to the use of landfill space. Of course this is allowed for by using the long-term average capacity rather than the normal operation capacity in the calculations, but then the transport costs are not properly represented - it is better to deal with the possible diversion of refuse more directly. Some care is needed in formulating the problem, however, or it becomes non-linear (and thus much more difficult for computation). In the event of a breakdown, the refuse from the collection round is transported to a landfill site rather than another incinerator, since there would not normally be any spare capacity at other incinerators, whereas landfills are assumed to have no limits on their rate of input and to be entirely reliable). This cannot be modelled as part of the normal flow from collection direct to landfill, however, since it might then be zero when there is some use of incineration; nor can it easily be treated as a subsidiary activity to incineration. Although there are several ways in which it can be formulated, the most satisfactory, in conceptual and computational respects, seems to be to regard incineration and diversion together as a single activity. In other words it is not possible to assign refuse to incineration plant *i* alone; it must be assigned to (if plant *i* is working then plant *i* else site *j*), a disposal strategy which is reliable.

From a conceptual point of view, this has the advantage of underlining the fact that it is a strategy rather than a day-to-day programme that is being selected, and for

this purpose incinerators without landfill for backup are not a possible choice; it also makes it possible to attach a cost to such a strategy which is not simply the weighted sum of the transport costs to incineration and landfill. This last point may well be significant; if the emergency landfill is much farther from the collection centroid than the incinerator, it may be necessary to provide extra vehicles for the collection round used, only on the occasions when the landfill site must be used, and this will involve continuous extra expenditure. It might be realistic to assume that the transport cost of such a strategy would be the larger of the two costs (to landfill and to incineration); this may be slightly pessimistic in practice, since some overtime working in the event of a breakdown is accepted, but clearly for a very distant landfill the point would need consideration.

In computational terms, the advantage of this formulation is that it increases the number of activities in the model (with m incinerators and n sites, there are mn rather than $m+n$ possibilities), but not the number of constraints (if incineration and diversion were treated separately, there would be an extra constraint for each centroid to ensure that enough diversion capacity was provided for the amount of incineration used). With practical linear programming packages, the computing time depends almost entirely on the number of constraints rather than the number of activities.

Including all these considerations, the model may be stated as follows:

Minimise

$$\begin{aligned}
 (C) \quad & \sum_{ijt} c_{ijt} x_{ijt} + \sum_{ijt} c_{jt} x_{ijt} + \sum_{jkl t} c_{jkl t} x_{jkl t} + \sum_{ikl t} c_{ikl t} x_{ikl t} + \sum_{jlt} c_{jlt} x_{jlt} \\
 & + \sum_{ilt} c_{ilt} x_{ilt} + \sum_{klt} c_{klt} x_{klt} + \sum_{klt} c_{kt} (\sum_j x_{jkl t} + \sum_l x_{ikl t}) \\
 & + \sum_{lt} c_{lt} \left\{ \sigma_c (\sum_j x_{ilt} + \sum_i x_{ilt} + \sum_{jk} d_{jk} x_{jkl t} + \sum_{ik} d_{ik} x_{ikl t}) + \sigma_r \sum_k x_{klt} \right\}
 \end{aligned}$$

subject to

$$(A) \quad \sum_j x_{ijt} + \sum_{kl} x_{ikl t} + \sum_l x_{ilt} = a_{it} \quad \text{for all } i, t;$$

$$(Y) \quad \sum_i x_{ijt} - \sum_{kl} x_{jkl t} - \sum_l x_{jlt} = 0 \quad \text{for all } j, t;$$

$$(X) \quad r_j < \sum_i x_{ijt} < q_j \quad \text{for all } j, t;$$

$$(J) \quad \sum_{jl} (1-d_k) g_k x_{jkl t} + \sum_{il} (1-d_k) g_k x_{ikl t} - \sum_l x_{klt} = 0 \quad \text{for all } k, t;$$

$$(I) \quad \theta_k < \sum_{jl} x_{jkl t} + \sum_{il} x_{ikl t} < b_k \quad \text{for all } k, t;$$

$$(T) \quad \sum_t \theta_t \left\{ \sigma_c (\sum_j x_{jlt} + \sum_i x_{ilt} + \sum_{jk} d_{jk} x_{jkl t} + \sum_{ik} d_{ik} x_{ikl t}) + \sigma_r \sum_k x_{klt} \right\} < v_t \quad \text{for all } t.$$

$$\sum_{ik} d_{ik} x_{ikl t} + \sigma_r \sum_k x_{klt} < v_t$$

Here i labels the collection centroids,

j the transfer stations,

k the incineration plants,

l the landfill sites,

and t the time periods.

The x 's are flows, and the c 's costs, which can be identified by their subscripts. All flows are in units of tonnes per annum, and costs are in pounds per tonne, except those for landfill operation which are in pounds per cubic metre.

The significance of the other symbols used is as follows:

- σ_c is the specific volume (cubic metres per tonne) for crude refuse in landfill sites;
- σ_r is the specific volume for incinerator residue (also in m^3/t);
- d_k is the fraction of the time for which incinerator plant k is out of operation and refuse must be diverted (this is assumed to be independent of time, as are all the following plant parameters);
- r_j is the minimum acceptable flow through transfer station j ;
- q_j is the maximum capacity of transfer station j ;
- g_k is the weight reduction factor for incinerator k , i.e. the ratio of the weight of residue produced to the weight of crude refuse input;
- e_k is the minimum acceptable input to incinerator k ;
- b_k is the maximum capacity of incinerator k ;
- v_ℓ is the volume (in cubic metres) of landfill site ℓ ;
- z_t is the length (in years) of time period t ;
- a_{it} is the weight of refuse (in tonnes per annum) arising at collection centroid i in period t .

The letters labelling the constraints are those used to name the rows in the matrix for input to the computer program, and their significance is as follows:

- (A) requires the total amount of refuse leaving centroid i to equal the total arisings there;
- (Y) requires the input to transfer station j to equal its output;
- (X) requires the flow through transfer station j to lie

between the specified maximum and minimum quantities - if the lower bound is zero, it may be omitted (since all the x 's, as usual, must be > 0 , though this is not stated explicitly above), while if it is equal to the upper bound, a single equality constraint can be used;

- (J) requires the amount of residue produced by the input to incinerator plant j (the actual, rather than the maximum theoretical input neglecting breakdowns) to correspond to the amount of residue transported to landfill sites;
- (I) requires the input to incinerator k to lie between the specified minimum and maximum, and the same comments for special cases apply as for (X);
- (T) requires the total input to landfill site l to be not more than the volume of the site - the constraint may be an equality if it is required to fill the site at or before the end of the planning period.

Since this is no longer a network flow problem, the Ford-Fulkerson algorithm cannot be used to solve it. It is a fairly substantial LP problem - having typically about 250 rows and 1500 columns for the data used - so the available routines for simple LP examples, which require all the matrix coefficients to be held in core, are not usable. It was decided that, despite the disadvantages noted above for the use of a package with matrix generator, the only immediately practicable way of tackling this problem was to use the ICL linear programming package (ICL (1969)) with a matrix generator (Appendix F), which was adapted from the previous complete program, and requires

input in a very similar form (Appendix A). The output from this program, in the format required for the SHARE linear programming system (also acceptable to the ICL package) was typically more than 6500 lines long; clearly it would not be practicable to conduct many experiments using this formulation of the problem and realistic data without the aid of a matrix generator. The need to use this approach is the reason for formulating the problem in terms of annual flows, rather than flows in a given time period, since as noted above, the latter is more convenient in the final output. The matrix generator also incorporates the model used for the cost of the disposal strategies involving incineration. Both the cost models discussed above - the weighted sum of transport costs to disposal and landfill, and the higher of the two costs - were used at different stages of the research, though the weighted sum was more usual.

After the model had been in use for some time, a reference was found (Beale (1968)) which suggested that the number of non-zero elements in the LP matrix was even more important than the number of rows in determining the computing time for a problem; "it is normally not worth saving a row if this adds more than about half a dozen non-zero matrix elements" (p. 83). In view of this, an alternative formulation was considered, in which the transport to incineration and to landfill (whether for diversion from an incinerator, or in the course of normal operation) were regarded as separate activities, and constraints were imposed to ensure that the required amount of diversion capacity was provided for each collection

centroid and transfer station. With this formulation, the use of the "weighted sum" model of transport costs is unavoidable in an LP approach. With typical data representing the West Midlands situation, the resulting LP problem (produced by the matrix generator program) had 372 rows, 885 columns and 4120 non-zero elements; the original formulation gave 247 rows, 1527 columns and 6885 non-zero elements. Thus 2765 non-zero elements were saved in this formulation, at the cost of an extra 125 rows - well within the criterion given by Beale. The two LP problems were solved using the ICL package referred to above, with identical control procedures. The running time for the LP package (including input and output) was 1012 seconds for the original formulation, and 960 seconds for the alternative; to compile and run the matrix generator took 130 seconds for the original formulation and 105 seconds for the alternative. Thus a total of 77 seconds (7%) was saved using the alternative formulation. There was no significant difference between the solutions obtained. If the weighted sum model is to be used for the transport costs, some saving can thus be made by adopting the alternative formulation, which can be stated as follows:

Minimise

$$\begin{aligned}
 \text{(C)} \quad & \sum_{ijt} c_{ijt} x_{ijt} + \sum_{ijt} c_{jt} x_{ijt} + \sum_{ikt} (1-d_k) c_{ikt} x_{ikt} + \sum_{jkt} (1-d_k) c_{jkt} x_{jkt} + \sum_{ilt} c_{ilt} x_{ilt} \\
 & + \sum_{jlt} c_{jlt} x_{jlt} + \sum_{kt} c_{kt} \left(\sum_j x_{jkt} + \sum_i x_{ikt} \right) + \sum_{klt} c_{klt} x_{klt} \\
 & + \sum_{lt} c_{lt} \left\{ \sigma_c \left(\sum_j x_{jlt} + \sum_i x_{ilt} \right) + \sigma_r \sum_k x_{klt} \right\}
 \end{aligned}$$

subject to

- (B) $\sum_k d_k x_{ikt} - \sum_l x_{ilt} < 0$ for all i, t ;
- (A) $\sum_k d_k x_{ikt} + \sum_k (1-d_k) x_{ikt} + \sum_l x_{ilt} = a_{it}$ for all i, t ;
- (Z) $\sum_k d_k x_{jkt} - \sum_l x_{jlt} < 0$ for all j, t ;
- (Y) $\sum_i x_{ijt} - \sum_k (1-d_k) x_{jkt} - \sum_l x_{jlt} = 0$ for all j, t ;
- (X) $r_j < \sum_i x_{ijt} < q_j$ for all j, t ;
- (J) $g_k (1-d_k) (\sum_i x_{ikt} + \sum_j x_{jkt}) - \sum_l x_{klt} = 0$ for all k, t ;
- (I) $e_k < \sum_i x_{ikt} + \sum_j x_{jkt} < b_k$ for all k, t ;
- (T) $\sum_t z_t (\sigma_c (\sum_i x_{ilt} + \sum_j x_{jlt}) + \sigma_r \sum_k x_{klt}) < v_l$ for all l .

The significance of the symbols is as above, except that x_{ilt} and x_{jlt} include waste sent to landfill either due to diversion from an incinerator or in the course of normal operation, and x_{ikt} and x_{jkt} are amounts that would be sent to incinerator k in a year when no breakdowns occurred (whereas the amount included in x_{ilt} and x_{jlt} for diversion is the expected quantity, i.e. for a typical year). The additional constraints are:

- (B) requiring the amount sent to landfill from collection centroid i to be adequate for diversions from the incinerators used

and

(Z) making a similar provision for the output from transfer station j.

6.3 Examples of the Use of the Models

To illustrate the effects of the different assumptions used in the models, and the analysis of their results, the two systems described above were used to assess the value of a possible transfer station to serve the Walsall/Sandwell area, and of the potential landfill site at Birch Coppice. The data used were based on the figures in chapters 4 and 5, and are shown (in the form required for input to the computer program for the first model) in Appendix D. Appendix G shows the data in the form required for the second model. The basic assumptions made were as follows:

- A period of ten years was considered;
- The possible transfer station and landfill sites become available after two years;
- A fall of 1% per annum in refuse arisings was assumed;
- A discount rate of 10% per annum was applied to all costs, and the output shows net present values in all cases;
- Costs of 4.2 p/tonne-minute and 1.28 p/tonne-minute, for collection and bulk vehicles respectively, were used;
- For the second model, it was assumed that the cost of transport from a transfer station to a combined incineration/landfill strategy would be the weighted sum

of the costs to the two sites, whereas for collection rounds the larger of the two costs was used;

- The costs assumed for treatment plants were the variable costs found in chapter 5, net of income from metals recovery (tables 5.6 and 5.8);
- A cost of 35 p/m³ was assumed for landfill space, and densities of 2.5 m³/t for crude refuse and 1 m³/t for incinerator residue were used;
- For the first (pure transshipment) model, the incinerator throughputs were given upper and lower bounds corresponding to the "actual" and "probable" throughputs (table 5.7), and for the second model bounds of 90% and 100% of the "budget" throughput were used;
- For the second model, the weight of residue from all incinerators was assumed to be 33.5% of the input, and it was assumed that all incinerators would divert refuse for 15% of the time, i.e. would be available 85% of the time;
- Travel times used were those derived from measured distances and estimated speeds, as described in section 5.1.2.

This "standard" set of assumptions was used for runs with both models, in which the effect of excluding the Walsall/Sandwell transfer station or the Birch Coppice site (otherwise assumed to be available) was assessed. With the first model, the same calculations were also carried out under two alternative sets of assumptions:

- (1) the refuse arisings increase by 1% per annum, rather than decreasing as in the "standard" assumptions;

(2) the cost of providing landfill space rises at 10% per annum in real terms, rather than remaining on a par with other costs as in the "standard" assumptions.

The total costs (net present values from a ten-year period) calculated under each of these sets of conditions are shown in Table 6.1.

It will be seen that the value of the Walsall transfer station is relatively small - only about £80 000, even using the "transshipment with gains" model (which because of the assumptions made on transport costs, is probably unduly favourable to transfer stations). The cost of building the station is not accounted for in the calculation, and would certainly be substantially greater than £80 000, so according to these calculations, it would not be worth constructing the station. It is, of course, possible that a different site for the station would have given a different result - the site assumed was midway between Walsall and Sandwell, and a site closer to either one might be preferable.

The value of the landfill site varies more widely, from £15 000 to £40 000, depending on the assumptions. In this case it is important to remember that an allowance for the cost of landfill space ($35\text{p}/\text{m}^3$) is included in the calculation. Allowing for discounting, the cost assumed for this site in the cases where it is used are approximately £13 200, £41 100, £22 500 and £49 300 in the four cases. Thus the net values of the landfill in the four cases are about £31 400, £82 000, £38 100 and £87 800 respectively. It is interesting that the value of this site is not much affected by rising costs at other

TABLE 6.1 COSTS ESTIMATED BY MODELS UNDER DIFFERENT ASSUMPTIONS

ASSUMPTIONS	COST (thousand £)				VALUE (thousand £)	
	STANDARD		NO TRANSFER		NO LANDFILL	
	NO TRANSFER	LANDFILL	NO TRANSFER	LANDFILL	TRANSFER	LANDFILL
TRANSHIPMENT MODEL						
Standard conditions	9 619		9 693	9 637	74	18
Higher arisings	10 503		10 571	10 544	68	41
Rising tip costs	9 883		9 965	9 899	82	15
TRANSHIPMENT WITH GAINS MODEL						
Standard conditions	14 451		14 532	14 489	81	38

(All figures have been rounded off to the nearest £1000)

sites, but rather depends on the demand for landfill space. This is much higher if rising waste production is assumed, or incinerator residue and diversions are taken into account, than in the other cases. Clearly further investigation of the likely arisings would be needed if a more accurate figure for the value of this site was required. It is likely that the use of the transshipment with gains model, assuming an increase in arisings, would produce a still higher valuation for the site.

Comparing now the results of the different models, the most obvious difference is the much higher figures produced by the transshipment with gains model compared to the pure transshipment version. This is of course due mainly to the inclusion of the costs of dealing with incinerator residue in the former model. This results in substantially more use of landfill space, as well as greater transport costs. The actual flow systems produced are also quite different. Nevertheless, in the case of the transfer station evaluation at least, the pure transshipment model gave results agreeing quite well with the more sophisticated system when finding the value of a particular facility.

These results make it clear that the costs estimated by this kind of system are quite sensitive to the assumed conditions (the apparently slight change from 1% fall to 1% growth in arisings resulting in a change of about 10% in the total costs calculated), and also, in some cases at least, to the type of model used. It is undesirable, therefore, to base major strategic decisions, involving

very large expenditure, on the results from one model with one set of assumptions. Comparison of several plausible sets of future conditions, preferably with several completely different types of model, will give the decision-makers a clearer idea of the inaccuracies in the estimates they are using.

6.4 Possible Extensions to the Current Models

The models discussed above are, from the point of view of an operational researcher, fairly obvious ways of approaching the problem of strategic planning in waste management. They do, however, suffer from a number of defects; whether or not these have a significant effect on the results produced is difficult to ascertain without trying alternative methods, and unfortunately time did not allow this in the present study. Some developments of the original concept of linear programming do, however, seem to offer possibilities for a better representation of the problem in certain respects.

One such development is chance-constrained programming (Charnes and Cooper (1959)). This appears to offer some advantages in dealing with the variations in refuse arisings, discussed in section 4.5. It allows the constraints in a linear programming problem to be relaxed to the extent that they are required to hold only with a specified probability, rather than with certainty - some of the parameters, in this case those specifying the arisings for each centroid in each time period, are taken to be random variables (with a given probability

distribution) rather than constants. For decision-making purposes, we require definite values rather than probability distributions to be found for the decision variables, so it is necessary to find a deterministic equivalent to the chance-constrained problem (Charnes and Cooper (1963)). When this is done for the case in question, it turns out that there is a simple interpretation of the result (Vajda (1972)). The chance constraint

$$\text{Prob } (ax > b) > \alpha,$$

where the distribution of b is

$$\text{Prob } (b < z) = F(z),$$

is equivalent to

$$ax > B\alpha = F^{-1}(\alpha).$$

The (rather obvious-sounding) physical interpretation of this is that if we require the arisings to be handled with probability α , we must use a figure for the arisings which will only be exceeded with probability $1 - \alpha$.

Unfortunately, this useful-looking result cannot readily be applied to the multi-time-period model used so far, because of its effect on the parts of the model dealing with tip space usage (the difficulty with fluctuations of arisings, as pointed out previously, is essentially connected with processing plants rather than tip sites). A plausible figure for the required probability might be, say, 95%; because the fluctuations in arisings are quite large, the figure for arisings which would not be exceeded for more than 5% of the time would be very much larger than the average arisings, and the cumulative

effect on the volume of tip space which would (according to the model) be required would be drastic. To give proper results for this aspect, the most likely (average) figure for the arisings must be used. Ideally, a much more complex model can be imagined, at any given moment, and abandoning the concept of pre-determined flows in the network in favour of determining limits within which the flows could be random. It seems likely that the computational requirements for such a model would be prohibitive, if (as at present) the aim were to be to compute an expected cost over all possible situations. Such an approach might be feasible in the context of a simulation, rather than an optimisation, model; this possibility, discussed below, would represent a major change in the aims of the project and has not been investigated in any detail.

Another possible extension of the model is the explicit use of multiple objectives. The discussion in chapter 2 shows that in practice there are many aspects, other than the cost, which must be taken into account when evaluating a strategy. In the work so far, it has been assumed that such points are considered outside the framework of the model. The difficulty in incorporating them is that, in general, the optimum system for each objective will be different; to find any overall optimum, it is necessary to assign relative weights to the different objectives. This is clearly a political decision, which should therefore be taken by elected members. However, it is framed in a rather technical form, making it difficult for them to

assess; in many systems using multi-objective techniques, the valuations are all required at the start of the calculation, which can also cause subjective difficulty. Other systems allow for an iterative exploration of possible solutions. A number of solutions can be identified which are "efficient" in the sense that, starting at such a solution, no change can be made which will improve the value of one objective without detriment to others. Whatever the weights chosen, the final solution will be of this type. This approach is discussed by Benayoun et al (1971) from the computational point of view, while Haimés, Hall and Freedman (1975) give a more conceptual discussion, and also consider the presentation of trade-offs between different objectives.

A similar technique, called Paretian environmental analysis, is applied to solid waste management by Kuhner and Harrington (1975). They point out that there may be a number of strategies with very similar values of the overall objective (be it total cost or any more elaborate function), but which differ greatly in their impact in particular respects (they consider particularly the effect on individual communities of a policy planned on a larger scale, but the same argument could apply to considering environmental or other effects regardless of their geographical distribution). They therefore suggest that all solutions whose total cost (still the primary criterion) is within some arbitrary tolerance of the minimum attainable should be examined, to determine their other effects. This is a very attractive approach. The

consideration of other effects after optimisation on one objective can be compared to the provision of information on the costs incurred by the district authorities in the models described above, with the added feature that a range of different solutions are presented. This allows concessions to be made to avoid extreme inequalities between the districts' costs, while the overall cost to the county remains the primary consideration. This method should not, however, be used to deal with environmental effects which may be of major importance, because it is assumed from the outset that the importance of the secondary objectives is small compared to that of the primary one - this is the justification for considering only a small range of solutions near the primary optimum.

The idea of considering a range of possible solutions leads on to consideration of another weakness of the present models. This is their assumption that, however many time periods into the future are modelled, all decisions must in effect be made immediately in order to calculate the operating costs of the system for the future. This is a less serious problem with the models used in this work than with those which select the optimum choice of capital investments such as new plant, but it is still of some significance. The problem arises because the state of affairs in the future cannot be predicted accurately - arisings, unit costs and even the priorities of the various objectives cannot be forecast with any confidence for as long as ten years ahead. Consequently, it is better not to make any decisions before they are

needed; managers prefer to "keep their options open". The present deterministic approach requires a commitment to the forecasts made now, and if these turn out to be seriously wrong, it may also turn out that the decisions made and implemented with their support hinder rather than help the waste managers of the future.

Rosenhead, Elton and Gupta (1972) propose an alternative approach, based on the concept of "robustness". They suggest that a range of possible future conditions should be considered, and decisions which must be made now should be made on the basis of how adaptable they are to different situations, rather than how well they deal with the most probable situation (a more precise discussion of the criteria to be used is given by Caplin and Kornbluth (1975)). To some extent, the use of the simple models for assessing the transport cost, as discussed earlier in this chapter, rather than sophisticated fixed-charge models which find the optimum capital plant programme as well, allows for this sort of point to be considered. Caplin and Kornbluth suggest the use of dynamic programming as a technique for solving the problem computationally; for the kind of problem dealt with in this study, a branch and bound type of approach would seem to be a possible way of implementing this proposal. The computational requirements, while substantial, should be no greater in total than those for examining the same range of alternatives with the existing system. However, the provision of a computer system to perform the calculations would be relatively awkward, as it would be necessary either to link the present linear programming package to another program, or to provide

routines for large-scale linear programming within another program. These difficulties made it impossible to implement this approach in the present research.

On a purely technical note, the multi-period network flow problem seems well suited to the use of decomposition. This is a device whereby large linear programming problems are "decomposed" into smaller elements, which are linked together by a few variables (in this case, the inputs to landfill sites in different time periods) into a "master problem". The point of this is that appreciable reductions in computing time may be made. The technique is discussed by Beale (1968). It might be possible to use the solution found for one time period as an initial solution for the others, thus reducing the computing time even further. Again, the difficulties of actually implementing such an approach with the software available made it impossible to try this in the present research.

The question of the computing time used for a particular model may seem peripheral, since in any case the cost is very small compared to the expenditure involved in the Waste Disposal Plan. This, however, is not the point; rather it is a matter of the way in which the model is to be used. If the time taken is only a minute or so, as with the FORTRAN program described in section 6.1, it is possible to use it interactively to try out ideas as they arise, and to gain some "feel" of the situation. Such a model can be built into a "game" of the kind described by Wahi and Peterson (1972), for use directly by the decision makers (senior officers, perhaps even committee

members, in the local authority context). With a system requiring half an hour or so, like that described in section 6.2, this is no longer possible; if the computer facilities are fully loaded, such a job might only be run overnight or at other times when demand is relatively low. If a more elaborate system requiring many hours of computer time were produced, it could be used only relatively infrequently (perhaps once a week or month), unless it was provided for when the computer facilities were set up (and if this were the case, the cost implications might well become significant). Thus the first kind of model can be used to test ideas, for instance, in the course of a meeting; the second can report on a suggestion within a few days, but does not provide the same "feel"; the third might provide responses to suggestions from one monthly committee meeting in time for the next. Each of these types of use may have its place; the third case, though it would be unacceptable for many purposes, might still be of some use in strategic planning of the kind considered here, where it is not unreasonable to envisage a delay of many months before a final decision is reached. Because relatively fewer possibilities can be examined in the slower systems, more care must be exercised in producing the data for them, and it is probably worth using one of the quicker systems for a time to ensure that the requirements have been fully understood and that the data will produce the results which are required.

7. CONCLUSIONS

In some respects, the research described in this thesis may seem rather inconclusive. In particular, the initial vision of producing a comprehensive model to analyse strategic decisions in waste management has not been fulfilled. Rather, such a possibility now seems even further from realisation than at the outset.

In fact, however, the very difficulty of the problem is a most important point. This work identifies the areas of difficulty, in which further effort will be needed before the problem of waste management strategy can be thoroughly understood. It is often supposed that the scientific approach, especially with the aid of computers, can solve virtually any problem. This is certainly not true unless the problem is well stated and the necessary information is available (and may not be true even then). The major needs in the present problem are for better information and more effective techniques for dealing with the lack of information. Because only the technical aspects of the problem are to be dealt with by the model (i.e. the value judgements should, as far as possible, be left for the elected members to make), some difficulty in the definition of the problem also arises, though in practice this has been less important than the other difficulties mentioned.

From another viewpoint, the essence of the difficulty is to define the extent to which the waste management system is flexible in different respects - the organisation of

collection rounds, the operation of treatment plant, the choice of strategic objectives and so on. Examples of the importance of flexibility in the current work are the difficulty experienced in defining the capacities of treatment plant, the concept of incineration with back-up landfill as a single disposal option (allowing some flexibility at the operational level) and the alternative ways of estimating the costs of transport for this disposal option. In general, the greatest difficulty in applying mathematical models to this kind of problem is to allow sufficient flexibility - it is quite easy to analyse a very rigid arrangement and determine the best way to use it (given some definition of "best"), but a more adaptable system may be capable of even better performance under real conditions, even though it cannot be optimised to the same degree. Indeed, the "Law of Requisite Variety" (Ashby (1956)) states that a control system must have as much variety in its responses as the system it controls has in its behavior, or it cannot maintain control. The great complexity and variability of the waste generation processes suggests that waste management (viewed as a control system) must be highly adaptable in order to cope with the situation at all.

The above conclusions are given in very general terms; there are a number of more specific conclusions and recommendations that can be drawn from the experience gained in this research. Some of these will be immediately applicable, with little or no further development, in the

preparation of strategic plans. Others will require some time to arrange and bring into effect, or should undergo some additional study and testing before they can be regarded as usable in practice, while a few clearly demand very substantial investment of time and effort and must be regarded as speculative.

7.1 Suggestions for Immediate Use in Planning

Despite the various reservations felt about the systems used in this research, it is clear from the reactions of the "users" in the West Midlands County Council that they do provide valuable information for the strategic decision-maker. The two overall models of the strategic waste management problem, described in chapter 6, seem to be at least as good as any others which are operating (rather than projected) at present; in some respects, each of them has advantages over other systems. Their continued use, and development as necessary, is therefore recommended. (It is understood that the relevant computer programs are now being implemented on the West Midlands County Council's own ICL 1904S computer). The position of the models of future waste arisings is less clear; their results have often been subjectively unacceptable, and seem to have had less impact on actual decision-making than the overall models. This may be because the results have large margins of uncertainty, or because they conflict with expectations (the indications of falling domestic waste production, for instance). If the latter is the case, then it may be worth retaining

some such models as a stimulus to more careful consideration of subjective predictions - it is clear that a large element of subjectivity must be present in such predictions, at least in the current state of knowledge.

Some small developments to the computer programs for the overall decision models would be worth making. For interactive use of the pure transshipment model (Appendix B), it would be useful to provide output of the quantities handled by each treatment plant and landfill site at the terminal - the present system provides only costs in this way. This change would allow more effective use of the interactive facility, making it possible to take factors other than cost into consideration immediately. Details of the pattern of movement from sources to sinks need not be provided interactively, but should be available off-line when required. It would be useful to provide a table of the actual costs in each time period, as well as the discounted figures (net present values) currently produced. Some extensions may be needed to cope with industrial wastes, when their inclusion in the strategic planning is required (and the necessary data are available). Sites producing industrial waste can readily be included in the models in the same way as household waste generation centroids, and linked to appropriate treatment and disposal facilities. The main problem is that although provision already exists for showing the costs for various collection operations separately (intended to show the costs incurred by each district), all treatment and disposal operations are assumed to be carried out by the county

authority and costed together. A small change to the program could cater for this, making it possible to indicate the costs incurred by waste disposal firms (as estimated by the model). It would probably also be necessary to provide for a larger number of different cost rates for different types of vehicle - this is also a fairly minor change. In the case of the transshipment with gains model, only the latter point would be relevant, since the output is not analysed into the separate costs as it is in the pure transshipment model.

The input data required by the programs must also be maintained in a state as close as possible to the current best information. It has been found that choosing appropriate figures on costs and capacities is much more of a problem than is usually assumed. The discussions of costing in chapter 5 should be carefully considered in order to provide the correct form of data for each system. Any improvements in estimates for costs or capacities, or changes in policy affecting capacities, would be important. More than one set of future conditions should be considered, since (as shown by the results of section 6.3) the likely uncertainties in the figures for future conditions lead to substantially different results from the models.

Particularly if some attempt to include industrial wastes is to be made, it is important to formulate as clearly as possible the Council's policy on the objectives to be sought in the waste disposal strategy. One aspect of this is the possibility referred to above of including

the costs incurred by private waste disposal operations in the optimisation procedure. Other areas where clearer direction is needed are the treatment of environmental impacts and system reliability (the second of these also presents some technical modelling problems which will be raised in section 7.3).

7.2 Suggestions for Immediate Study

Perhaps the most serious difficulty experienced in this research was the lack of well-defined, regularly collected, quantitative information on the operation of the waste management system. It seems likely that this problem is not confined to the West Midlands County - rather, nearly all other counties seem to be even worse off in this respect. The most essential requirement for future planning, particularly if modelling and other quantitative methods are to be used, is that such data should be provided. The information currently available is intended for operational control and budgeting, rather than strategic planning. A reconsideration of the forms of data collected, and the depth of detail recorded, is therefore recommended; careful thought should be given to the information needs of the long-term planner. With the availability of computers for data analysis, it is probably now true to say that there is no danger of collecting too much detail to use; on the other hand, it is possible that the costs of data collection could outweigh the savings obtained by the use of the data. Unfortunately it is very difficult to give even a rough estimate of the savings obtainable without very detailed consideration of matters such as the

degree of reliability required of the waste disposal service and the costs of its failure (these would be relevant to the benefits of more accurate estimates of waste production, for instance). Intuitively, it seems unlikely that any waste disposal authority is near the point at which its data collection costs as much as it saves.

To be more specific about the information requirements, the quantity of waste collected (or otherwise arising) should be recorded, broken down in time and space as far as is convenient. "Quantity" should preferably mean "weight"; if not all vehicles are weighed, at least sample vehicles from various collection rounds should be weighed at regular intervals to provide an indication of the actual quantities being handled. Analyses of collected refuse are very useful, so long as the sample collection areas are carefully characterised to allow extrapolation to the whole county. The information extracted from these figures should include not only the expected quantities to be collected in future, but the degree of uncertainty in the predictions and the extent to which fluctuations are found from week to week.

At treatment plants, fairly good records of the activity of the plant are normally kept already. Apart from arranging them in such a way as to allow study of the collected quantities (as advocated above), the main need here is for more detailed information on the operating costs of the plant. It would be helpful if some indication could be obtained of the variation of cost with throughput,

though obviously the effect of short-term fluctuations will differ from that of long-term changes in policy (for instance, in the effect on labour requirements).

At landfill sites, apart from the record of incoming waste, it would be helpful to know the actual operating costs of different sites. A periodic survey of sites, to relate the volume filled to the input tonnage, would give some indication of the final densities produced by various techniques of management (cf. Bratley (1976); Briggs (1976)).

Most of the information set out above could be used directly as input to models of the sort described earlier. Where it could not (as, for instance, in the uncertainties in figures) it is useful in making a subjective assessment of the results from such models and is therefore of some immediate value. On the kind of time-scale now being considered, with a delay of one or two years before useful results can be expected, it is possible that improved techniques of analysis may emerge, requiring different forms of data for their application. However, the very complex problems which arise in attempting to extend the techniques used in this research suggest that rather longer delays are to be expected before significant changes can be implemented in models for strategic planning.

7.3 Suggestions for Long-term Investigation

Some of the difficulties encountered in this study seem to be fairly deep-rooted, in that they will require more effort for their resolution than those discussed in the preceding section. For instance, the division of

responsibility between county and district councils caused some (though by no means all) of the problems in modelling waste arisings and collection. This division was always somewhat controversial; it is possible that, in the fairly long term, the responsibility for waste collection and disposal will again be integrated. Most pressure at present seems to be directed towards larger geographical areas of responsibility in this field, i.e. towards the transfer of collection duties to the counties. For hazardous wastes, even larger scales, involving regional control, are being envisaged.

Rather in contrast to this move towards the unification of ever larger areas, there is the possibility discussed in section 6.4 of adopting a form of strategic planning that would not produce a "master plan" for a relatively long time ahead, but rather would make decisions only when necessary and seek to maintain as much flexibility as possible for the future - this might be regarded as decentralising the decisions in time. The main difficulty with this approach is the lack of methods for assessing the "robustness" of a particular strategy in practice. There is a need here for modellers to develop some way of representing this sort of decision which is reasonably easy to apply to real situations.

Another fairly major area where further research is needed is that of solid waste generation by households. The production of household waste, which for the time being at least is the main part of the wastes dealt with by local authorities, is a process which is not understood even in quite general terms. As a result it is impossible

to produce reliable predictions on the time-scale required for strategic planning, even given good information about the present waste production. A thorough study of the factors determining household waste production would be of great value for the future.

In general, it is clear that this study has only scratched the surface of a large body of problems; much more remains to be done. With the increase in public awareness of the importance of solid waste management, and in the cost of suitable waste management methods, a deeper understanding of both the mechanisms and the issues underlying waste management will be vital in the future. Such an understanding cannot be gained either in isolation from the actual activities of waste management, or in constant pre-occupation with the day-to-day running of the service. It is therefore to be hoped that collaboration between academic institutions and waste disposal authorities, to conduct further investigations of this area, will become more widespread in the future.

APPENDIX AA STATISTICAL STUDY OF REFUSE ANALYSES (1975 REPORT)A.1 Introduction

This study was undertaken as part of a research project in the Aston University Interdisciplinary Higher Degrees scheme, supported by the West Midlands County Council Waste Disposal Department. The overall objective of the project is "to produce a strategy for solid waste management in the West Midlands". The Council will be required to prepare a detailed plan for solid waste management under the Control of Pollution Act 1974, and this work was intended to provide information needed for this purpose.

One of the wastes to be considered in the plan is domestic refuse. In order to plan effectively, it is necessary to predict the quantity and nature of the domestic refuse to be expected during the period of the plan. This study attempts to provide a basis for such forecasting in the West Midlands area, by detecting and extrapolating trends in past analyses of domestic refuse. Seasonal variations in the analyses, and the effects of temperature and rainfall were also investigated.

Previous forecasts of domestic waste have been made on a national basis by A.E. Higginson (1966, 1970), and by the Working Party on Refuse Disposal (Sumner et al (1971)). Both noted the main national trends since the 1930's, of falling density and cinder content, increasing paper content and slowly increasing total weight, and produced forecasts for 1980, apparently on a subjective basis. The Local

Government Operational Research Unit produced a report (Green (1969)) recommending local rather than national forecasting, because of the importance of local variations in refuse composition. The method proposed was to assume a constant percentage growth in each component of the refuse, the growth rates being based on the predicted consumption of the material in question. A relationship between the density and paper content of refuse (derived from national data) was used to predict volumes. The predictions made by using this method on past refuse analyses from Birmingham do not agree with the subsequent observations, nor does the density - paper content relationship used fit the Birmingham data. This approach, therefore, seems to be inadequate in the present case.

A.2 Data

The principal source of data for this study was the record kept by the Salvage Department of Birmingham C.B.C. (and since April 1974 by the Waste Disposal Department of West Midlands M.C.C.) of refuse analyses performed by them at intervals since 1961. These were initially carried out for the Institute of Public Cleansing, and later for the Department of the Environment, for the compilation of national statistics.

The analyses are on the lines recommended by Higginson (1966). They are based on one week's refuse, as collected from four sample groups of dwellings. The groups used have remained the same throughout the series of analysis; they consist of three groups of 100 houses each, intended to represent 'artisan', 'middle-class' and

'residential' housing, and a group of 180 flats in centrally-heated high-rise blocks. The flats have two collections in a week; these are recorded separately, but have been aggregated for this study. The analyses have generally been made once a quarter, to give indications of seasonal variations, in Winter (3rd week in January), Spring (3rd week in April), Summer (3rd week in July) and Autumn (3rd week in October). The actual dates of the analyses have often departed by a week or two from this standard, and there are a number of gaps in the quarterly series, mostly in the period before 1966.

The weight and density of each sample as a whole is recorded, and the sample is then analysed into its various components. The classification used has varied in detail during this time, but is essentially as follows:

- a) Fine dust and cinder (screened through a $\frac{1}{2}$ " mesh until 1973, then a 2 cm mesh).
- b) Large cinder, $\frac{1}{2}$ " to $1\frac{3}{4}$ " (dropped as a class in 1973, now included under 'Unclassified').
- c) Vegetable and putrescible matter.
- d) Paper, cardboard etc.
- e) Metals
- f) Glass
- g) Rag
- h) Plastics (formally introduced as a class in 1971, but recorded as a sub-classification before this time).
- i) Unclassified.

The weight, and percentage by weight, of each component

is recorded. The total rainfall and the average temperature in the week of collection and the preceding week are also recorded, and it is noted whether or not a compaction vehicle was used for collection.

A.3 Analysis of the Data

This study considered the data on weight, density, percentages by weight of components (c), (d), (e), and (i), temperature and rainfall. These data were extracted from the records, converted where necessary into metric units (weights in kg/dwelling/week, densities in kg/m³, temperatures in °C and rainfalls in mm/week), and prepared in a suitable form for input to a standard statistical analysis program on the Aston University I.C.L. 1905E computer. The program was used to calculate overall values for the Birmingham area from the data for the four sample groups (see section A.4), and to calculate volumes of refuse (in m³/dwelling/week) from the weight and density data.

To detect trends in the data, the statistical technique of multiple regression analysis was used. The program represents the quantity of interest, called the dependent variable, by an equation of the form:

$$y = a + b + ct^2 + dt^3 + e/t$$

where y is the dependent variable, t is the time (measured in quarters, with Winter 1961 as $t = 1$), and a, b, c, d, e are constants, which are chosen by the program so that the equation represents the data as accurately as possible. If any of the terms in the equation are not statistically significant at the 1% level (i.e. there is more than a 1%

chance that the dependent variable does not depend on these terms at all), they will be omitted by the program. Thus if for example the variable being considered is constant in time, it will be represented simply by:

$$y = a$$

This type of analysis was carried out for each of the sample groups, and for the overall values, using the weights, volumes, and percentages of the components as dependent variables. A similar method was used to find linear dependence of weights and densities on rainfalls and temperatures. Seasonal variations in overall weight, volume and percentages of the components (except the 'unclassified' component) were also studied, by finding the average, for each season, of the difference between the data points and the trend curve (found above). If there is no seasonal variation, these advantages should not differ significantly from zero.

A.4 Overall Refuse from an Area

To produce overall figures for the quantity and composition of refuse from an area containing a mixture of different classes of housing, averages are taken of the figures for each class, weighted according to the proportion of that class in the area. To indicate roughly the relative importance of the different classes of housing in the West Midlands, weightings have been estimated for the Birmingham C.B.C. area on 1st April 1973. The numbers of houses and flats combined in different classes were estimated from rating statistics, and the number of flats from Neale and Haine (1974, table 78). The figures from

these sources are shown in Table A.1 and the rateable values of the sample groups in Table A.2. By plotting the cumulative distribution of house rateable values (Table A.3, Figure A.1), the numbers of dwellings to be represented by each of the sample groups can be estimated (Table A.4). In calculating the distribution figures for houses only (excluding flats), it was assumed that all flats fell into the interval £150-£400 in rateable value.

By finding similar figures for other areas, it will be possible to predict domestic waste arising in any part of the West Midlands, allowing for the different distributions of housing classes. This assumes that there are no significant differences between domestic waste in Birmingham and other parts of the West Midlands; this may be incorrect, for instance, in the more rural parts of the Solihull district.

A.5 The number of people per dwelling

The figures in the results for weights or volumes, rather than percentages, all refer to quantities per dwelling per week. The unexpected finding that many of these quantities have fallen in recent years led to a consideration of the variation of the number of people per dwelling over the period in question, in order to find the quantities produced per person per week. Figures for the numbers of people and dwellings in the Birmingham C.B.C area were obtained from Neale and Haine (1974, table 64), and are shown in Table A.5. Table A.6 shows the quantities of refuse per person, rather than per dwelling, for the corresponding times. (The quantities per dwelling taken

TABLE A.1Housing in Birmingham C.B.C. Area at 1st April 1973

Description	Number of Cases
Houses and flats, with rateable value: not exceeding £75	6920
Exceeding £75 but not exceeding £100	13287
" £100 but not exceeding £125	25620
" £125 " " " £150	39819
" £150 " " " £400	241190
Exceeding £400	5467
Municipal flats built since March 1945	41063

TABLE A.2Rateable Values of Sample Groups of Dwellings

Housing Class of Sample	Rateable Values (£)		
	Minimum	Maximum	Average
Artisan	163	218	165
Middle-class	214	547	280
Residential	626	1184	850
Flats	143	201	190

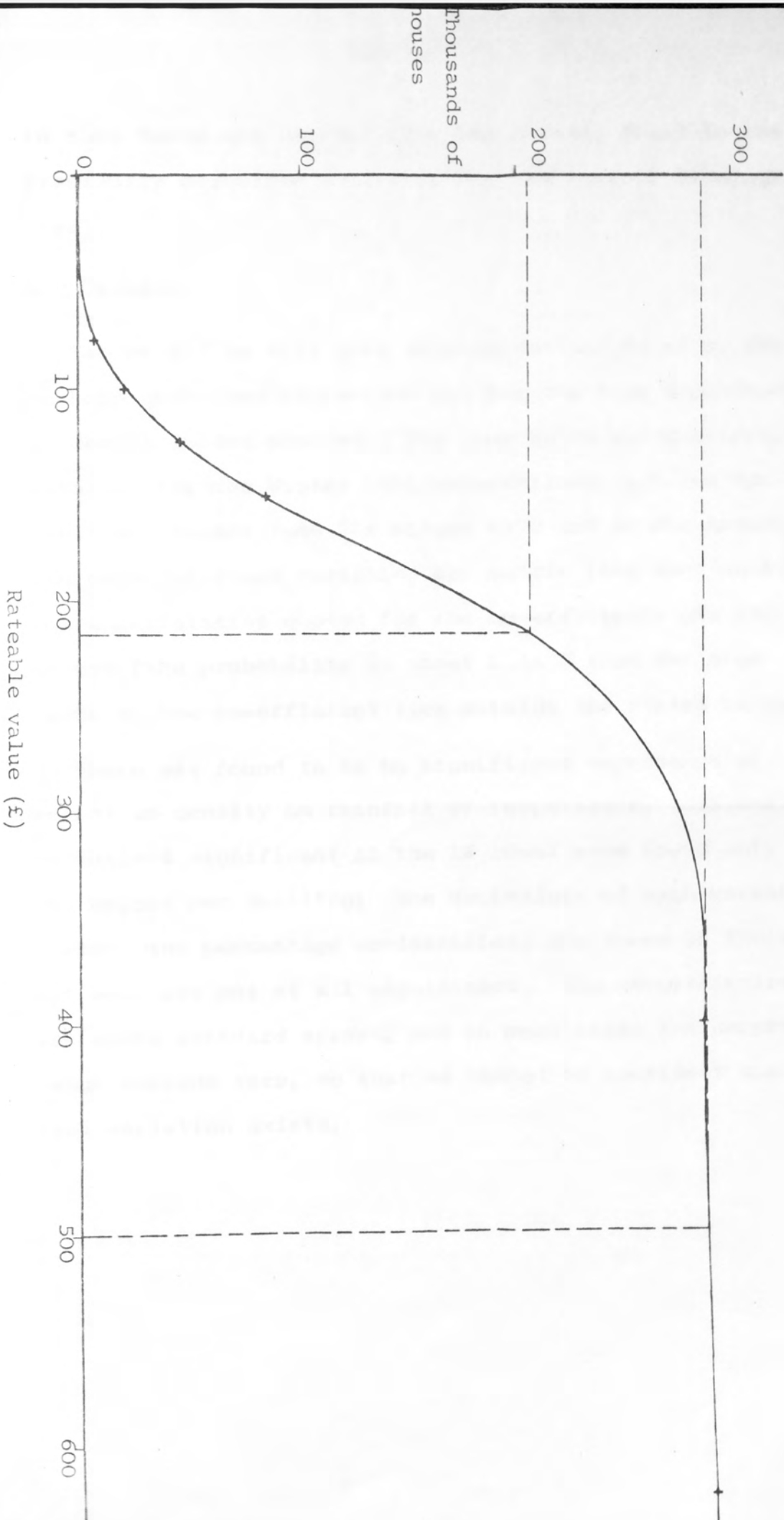
TABLE A.3Cumulative Distribution of House Rateable Values

Description	Number of cases
Houses with rateable value:	
not exceeding £75	6920
" " £100	20207
" " £125	45827
" " £150	85646
" " £400	285773
Total number of houses	291240

TABLE A.4Dwellings Represented by Sample Groups

Sample	Assumed to represent	Dwellings represented	
		Number	Percentage
Artisan	Houses of rateable value not exceeding £215	205000	62
Middle-class	Houses of rateable value between £215 and £500	82000	25
Residential	Houses of rateable value exceeding £500	30000	1
Flats	Municipal flats built since March 1945	41000	12

FIGURE A.1 CUMULATIVE DISTRIBUTION OF HOUSE RATEABLE VALUES



in this table are derived from the curves, found in the previously described analysis, for the overall Birmingham area).

A.6 Results

Tables A.7 to A.11 give representations found by the methods described in section A.3 for the time dependence of the variables studied. The time units are quarters, with $t=1$ for the Winter 1961 observations, $t=2$ for Spring 1961, and so on: $t=40$ for Autumn 1970 and 80 for Autumn 1980. The units of other variables are metric (see section A.3). The uncertainties quoted for the co-efficients are standard errors (the probability is about 1 in 3 that the true value of the co-efficient lies outside the stated range).

There was found to be no significant dependence of weight or density on rainfall or temperature. Seasonal variations significant at the 1% level were found only in the weight per dwelling; the deviations of each variable (except the percentage unclassified) are shown in Table A.12, but most are not at all significant. The uncertainties quoted are again standard errors, and in many cases the uncertainty range include zero, so that we cannot be confident that a real variation exists.

TABLE A.5Number of People per Dwelling in Birmingham C.B.C. Area

Date	Population	No. of dwellings	No of people per dwelling
1961	1,068,228	323,509	3.302
1966	1,035,740	325,320	3.184
1971	990,385	341,648	2.899

TABLE A.6Quantities of Refuse per Person per Week

Date	No. of people per dwelling	Weight/dwelling/week (kg)	Weight/person/week (kg)	Volume/dwelling/week (m ³)	Volume/person/week (m ³)
1961	3.302	14.534	4.402	0.0653	0.0198
1966	3.184	13.094	4.112	0.0653	0.0205
1971	2.899	11.654	4.020	0.0653	0.0225

TABLE A.7

Regression Equations - Artisan Dwellings

Variable	Representation	Units
Weight/dwelling/week	$(15.65 \pm 0.71) - (0.091 \pm 0.021)t$	kg
Volume/dwelling/week	(0.0652 ± 0.0017)	m^3
Vegetable and putrescible matter	(15.76 ± 0.85)	% (wt)
Paper	$(10.31 \pm 3.05) + (1.19 \pm 0.16)t - (0.000252 \pm 0.000049)t^3$	% (wt)
Metal	$(6.77 \pm 0.27) + (0.0000195 \pm 0.0000037)t^3$	% (wt)
Glass	(7.17 ± 0.18)	% (wt)
Unclassified	$(4.68 \pm 0.61) - (0.0100 \pm 0.0018)t^2 + (0.000232 \pm 0.000032)t^3$	% (wt)

TABLE A.8
Regression Equations - Middle-class Dwellings

Variable	Representation	Units
Weight/dwelling/week	$(13.06 \pm 0.47) - (0.0000186 \pm 0.00000065)t^3$	kg
Volume/dwelling/week	(0.0648 ± 0.0020)	m ³
Vegetable and putrescible matter	(15.66 ± 0.77)	% (wt)
Paper	$(18.37 \pm 2.51) + (0.92 \pm 0.13)t - (0.000199 \pm 0.000040)t^3$	% (wt)
Metal	(8.15 ± 0.33)	% (wt)
Glass	(7.49 ± 0.24)	% (wt)
Unclassified	$(3.11 \pm 0.57) + (0.00112 \pm 0.00037)t^2$	% (wt)

TABLE A.9

Regression Equations - Residential Dwellings

Variable	Representation	Units
Weight/dwelling/week	$(22.22 \pm 0.73) - (0.126 \pm 0.021)t$	kg
Volume/dwelling/week	(0.0975 ± 0.0022)	m^3
Vegetable and putrescible matter	(15.13 ± 0.69)	% (wt)
Paper	$(19.54 \pm 2.70) + (1.11 \pm 0.000290 \pm 0.000044)t^3$	% (wt)
Metals	$(6.01 \pm 0.29) + (0.0000114 \pm 0.0000040)t^3$	% (wt)
Glass	$(9.03 \pm 0.50) + (0.0000183 \pm 0.0000069)t^3$	% (wt)
Unclassified	$(4.01 \pm 0.70) - (0.0073 \pm 0.0020)t^2 + (0.000178 \pm 0.000037)t^3$	% (wt)

TABLE A.10
Regression Equations - Flats

Variable	Representation	Units
Weight/dwelling/week	(10.01 ± 0.17)	kg
Volume/dwelling/week	(0.0641 ± 0.0010)	m ³
Vegetable and putrescible matter	$(11.66 \pm 0.48) + (0.0000212 \pm 0.0000066)t^3$	% (wt)
Paper	(46.97 ± 0.84)	% (wt)
Metal	(7.15 ± 0.20)	% (wt)
Glass	$(5.53 \pm 0.41) - (0.0043 \pm 0.0012)t^2 + (0.000087 \pm 0.000021)t^3$	% (wt)
Unclassified	(4.41 ± 0.22)	% (wt)

TABLE A.11
Regression Equations - Birmingham overall

Variable	Representation	Units
Weight/dwelling/week	$(14.61 \pm 0.52) - (0.072 \pm 0.015)t$	kg
Volume/dwelling/week	(0.0653 ± 0.0013)	m ³
Vegetable and putrescible matter	$(22.77 \pm 2.01) - (0.177 \pm 0.052)t$	% (wt)
Paper	$(16.47 \pm 2.53) + (1.01 \pm 0.14)t - (0.000223 \pm 0.000041)t^3$	
Metal	$(6.95 \pm 0.24) + (0.0000163 \pm 0.000034)t^3$	% (wt)
Glass	(7.00 ± 0.17)	% (wt)
Unclassified	$(4.52 \pm 0.51) - (0.0071 \pm 0.0015)t^2 + (0.000166 \pm 0.000027)t^3$	% (wt)

TABLE A.12

Seasonal variations - Birmingham overall

Variable	Deviation from trend - Winter	Deviation from trend - Spring	Deviation from trend - Summer	Deviation from trend - Autumn
Weight/dwelling/week	$+ (0.81 \pm 0.37)$	$+ (0.59 \pm 0.29)$	$- (1.78 \pm 0.35)$	$+ (0.24 \pm 0.49)$
Volume/dwelling/week	$- (0.0009 \pm 0.0019)$	$+ (0.0058 \pm 0.0037)$	$- (0.0038 \pm 0.0018)$	$- (0.0009 \pm 0.0002)$
Vegetable and putrescible matter	$- (2.00 \pm 0.82)$	$- (1.38 \pm 0.98)$	$+ (2.13 \pm 1.24)$	$+ (1.58 \pm 1.23)$
Paper	$- (2.22 \pm 1.47)$	$- (0.60 \pm 1.66)$	$+ (3.85 \pm 1.67)$	$- (0.56 \pm 1.31)$
Metal	$- (0.25 \pm 0.39)$	$+ (0.06 \pm 0.28)$	$+ (0.29 \pm 0.43)$	$- (0.15 \pm 0.26)$
Glass	$- (0.22 \pm 0.23)$	$- (0.25 \pm 0.25)$	$+ (0.52 \pm 0.26)$	$- (0.07 \pm 0.26)$

A.7 Conclusions

a. Weight

With the exception of the flats, the weight per dwelling has been falling steadily over the whole period of the data, by roughly 2% p.a. The weight per person has also fallen, though by rather less (about 1% p.a.). This trend will presumably level off, and possibly reverse, at some time in the future (it will reach zero in about 2020 otherwise), but obviously we cannot tell from the data when this will happen. The weight is significantly lower in summer (about 10%) - presumably due to absence of many people for holidays.

b. Volume

Over the whole period of the data, the volume per dwelling was best represented as a constant. However, it appeared from the graphs that there had been a rise until about 1968, followed by a fall (again excepting the flats). A separate analysis was, therefore, carried out, using only the data from 1968 onwards; the results for the artisan and residential dwellings, and for Birmingham overall, showed a significant fall in this period, but the middle-class dwellings and flats gave results not significantly different from those for the complete data. The new results are given in tables A.13 and A.14. The volume per person shows a slow increase on the basis of the complete data, and a slow decrease for the more recent part. This is quite different from previous results (Higginson (1966,1970); Sumner et al (1971); Green (1969)), which all showed a substantial increase with time, and predicted that it would continue. This

may be associated with the fall in the paper content observed since about 1970 (see below), since paper is the major contributor to the volume of refuse.

c. Vegetable and Putrescible Content

The observations for this variable are very widely scattered. Though no trend is apparent in the results for individual groups, except for the flats, where a rise is found, the overall figure shows a clear fall. This must be because the averaging process has reduced the scatter sufficiently for the trend, which is not detectable in the original data, to become apparent.

d. Paper content

Here there is a dramatic change about 1970, the former steep increase being completely reversed. The attempt to extrapolate the trend here gives obviously unrealistic results (no paper at all in refuse by 1979), and we must expect a levelling off, and perhaps a return to the increasing trend, at some future date. When this change will occur cannot be predicted on the basis of the past trends, just as the 1970 change was not predicted, even in forecasts produced at about the time it occurred (e.g. Sumner et al (1971)). The change is probably due to the rapid growth of waste paper recovery for re-cycling (the flats, where the refuse disposal system does not lend itself to separate collection of paper, do not show the fall), so the present fall in waste paper prices may well lead to another reversal of the trend.

e. Metal content

There is a distinct rise overall, though it is not apparent in the results for middle-class dwellings and

TABLE A.13

Regression Equations - Volume per dwelling per weekBased on data since 1968 only

Type of dwelling	Representation	Units
Artisan	$(0.0904 \pm 0.0075) - (0.00063 \pm 0.00017)t$	m ³
Middle-class	(0.0666 ± 0.0030)	m ³
Residential	$(0.1514 \pm 0.0124) - (0.00126 \pm 0.00029)t$	m ³
Flats	(0.0628 ± 0.0013)	m ³
Birmingham overall	$(0.0928 \pm 0.0064) - (0.00067 \pm 0.00015)t$	m ³

TABLE A.14Volume of refuse per person per weekBased on data since 1968 only

Date	No. of people per dwelling	Volume per dwelling per week (m ³)	Volume per person per week (m ³)
1961	3.302	(0.0928)	(0.0281)
1966	3.184	0.0795	0.0250
1971	2.899	0.0662	0.0228

(The 1961 figures are bracketed because the regression equation does not provide a realistic fit to the data at this time).

flats. This probably reflects an increase in the use of tinned foods, and perhaps of aerosol containers instead of bottles.

f. Glass content

Despite rises in the glass content of refuse from residential dwellings and flats, there is no significant rise overall. (Artisan and middle-class dwellings together form 87% of all the dwellings in Birmingham, and so dominate the overall results).

g. Unclassified component

The chief feature here is an abrupt increase since the beginning of 1973, which has led to projections showing a continuing dramatic rise. These are not realistic; the increase is due to the inclusion of large cinder, since its separate classification was dropped, and this component will probably remain at about its current level. It is noticeable that the increase is not found in the data from the flats, where no cinders are expected.

It is important to remember, when considering the results, that they are based on the assumption that trends will continue as they are. In some cases, commented on above, this is obviously not true, and the change in the paper content trend since 1970 shows how drastic the effect of an unforeseen development may be. Such changes will only be detected by continued monitoring of refuse analyses.

A.8 An Alternative Approach to Forecasting

The method used in this study simply looks for trends in the data, without considering the underlying causes of the variations observed. These variations must be due to some (probably very complex) interaction of economic and social factors, and it would be more satisfactory to identify these factors as far as possible, in order to allow for anticipated changes. The present study implicitly assumes that the (unspecified) factors controlling refuse arisings will continue to vary as they have in the past, and without identifying these factors, it is not possible to tell whether this is likely to be correct. The dramatic change found in paper arisings since 1970 shows the potential importance of a change in the situation, which might have been predicted by a sophisticated forecasting system.

A better approach than used here would be to look for correlations between refuse arisings and economic variables such as gross national product, gross product of the area in question, or average income per capital in the area. It might also be possible to correlate the arisings of a given component of refuse (e.g. waste paper) with the levels of activity of the industrial sectors producing the material or consuming it (e.g. the rates of paper production and recycling). This will result in a form of "input - output" model, a class of models widely used in economics. Obviously it will require substantially more effort, particularly in data collection, than the simple approach used in this report.

It may be found that lagged correlations are present

(e.g. this year's refuse output depends on last year's income), and this will simplify short-term forecasting. However, long-term strategic forecasts are of more interest, and to use the suggested approach in this context, it is necessary to forecast the behaviour of each of the factors found to be significant. Such forecasts are likely to be available from the source of the original statistics (national or local government, or the industry concerned), and these will take into account developments in their fields, of which waste disposal staff may not be aware. Thus, this system should result in an improvement in forecasting accuracy (though forecasts made by outside bodies may need careful examination). Speculation as to the effect on refuse arisings of possible future events can be placed on a sounder basis, since the extent of the influence of the various factors will be known quantitatively.

APPENDIX BDETERMINING OPTIMAL REFUSE FLOWSB.1 Nature of the Problem

When planning waste disposal on a county-wide scale, it is necessary to choose between the possible schemes for future disposal arrangements (should we acquire landfill site 1, site 2, or both? Should we build a transfer station, and if so, where? etc.). One of the factors to be considered in making this choice is the operational cost of each of the schemes, of which a large part is due to the cost of transporting refuse from the collection rounds to the disposal facilities. This cost is almost impossible to assess properly by manual calculation, since it will generally be necessary to reorganise all the arrangements as to where refuse from a given round is to be disposed of, whenever a new disposal facility comes into use or an old one closes. It is desirable to plan for a number of years into the future, so that long-term implications of schemes, particularly with regard to landfill sites, can be seen. The computer program described here was developed to deal with this calculation. It finds a flow pattern giving the minimum possible cost, for a given set of collection and disposal points, and provides interactive facilities for altering the disposal points, so that the user can experiment to find the best arrangement. (It would be possible to arrange the program to perform this process, to find the set of disposal facilities giving the lowest cost; this has not been attempted,

since in practice there are many other considerations involved, which may be hard to quantify).

It should be noted that this system was designed for long-term planning, rather than the production of detailed operational plans. Although the flow patterns produced by the program will obviously be of interest when planning the operational arrangements, it must be recognised that they do not take account of the variability found in real waste-disposal operations, but are based on long-term averages. The practical situation will require more complex arrangements, and will result in higher costs, than in the idealised plan. It is assumed that the difference in cost between the real and ideal arrangements will be same for any of the schemes to be considered.

A particularly important example of this problem in the West Midlands concerns the operation of direct incineration plants. The experience of the West Midlands County Council is that these modern, highly-mechanised plants are prone to various forms of breakdown, and over a long period only burn about 85% of their design rating (usually quoted in tons per hour), although for short periods they may reach the design rating. During breakdowns, therefore, it is often necessary to divert refuse from the plant to an alternative disposal site. The present program cannot deal with this problem, and simply considers the long-term average plant intake. Thus, although the flow network it produces will result in the right quantity of refuse being delivered to a plant in a (typical) year, it will not provide sufficient

refuse in a week of good burning, or divert in a week of breakdown. With only one or two such plants, the necessary changes will be fairly simple, but in the West Midlands, with five direct incinerators operating, and another under construction, the possible interactions between plants become complex. An alternative system is available to deal with this problem, but as it is less convenient to use, the present system may still be found valuable.

B.2 Features of the program

The program, being intended for planning over a time-scale in which several changes in disposal facilities may take place, must be able to represent these changes. This is achieved by the idea of 'time periods'. Whenever a change occurs, there is a break between periods. There can be up to nine periods, or varying lengths. By specifying the periods in which disposal facilities open and/or shut, changes can be represented due to a new plant opening or an old one closing, and a requirement that a landfill site should be full by a given time can be included. If the characteristics of a plant were to change (e.g. a modification resulting in increased capacity), it would be possible to represent this as the closing of one plant and the opening of another at the same site. Continuous changes in the quantity of refuse arisings, and the various costs involved, can be represented as compound growth rates, which may be zero, or negative if a fall is predicted.

The costs assessed by the program include those of the movement of collection vehicles from their rounds to

the appropriate disposal point, and, if transfer stations are used, movement of bulk vehicles from these stations to final disposal. The operating costs of transfer stations, incinerators and landfill sites are also included. The "operating cost" is calculated as being proportional to the quantity of refuse handled, but in practice costs which vary in this way will be quite small, compared with the fixed costs of capital repayments and other overheads. Only those costs which do vary with throughput should be included when assessing this figure. Other costs, which do not vary with the flow through the system but may differ from one proposed system to another (for instance, capital expenditure on proposed new facilities), should be added to the final totals when comparing the overall costs of different schemes. Note that no account is taken of the disposal of incinerator residues, either in terms of the cost of dealing with them or of the need for landfill space to accommodate them. The cost could be included in the operating costs of incinerator plants, but this would mean that they would be fixed, whereas they should interact with the rest of the disposal system. The alternative computer system mentioned earlier also deals with this problem.

The cost of movements is assessed by determining the length of each route from a map, and estimating the speed expected on this route to find the time taken. From existing records, the cost per minute of operating the vehicles can be found, and divided by the average load to give the cost per ton - minute of transport. It is felt that, especially in urban areas like the West Midlands,

it is much more realistic to base calculations on time of travel rather than distance, as the speeds will vary widely, from perhaps 15 mph average in city streets to 35 mph or more on motorways. When measuring the distances, it is necessary to divide up the collection rounds into a number of points, from which to specify the quantity arising and the times of travel. Ideally, one might like to have a point for every collection round, but this would be an inconveniently large amount of data for a county-wide plan. In practice, the county should be divided up into a convenient number of collection areas, along natural boundaries as far as possible, and a 'centroid', or 'centre of gravity', chosen in the area, as a point from which to measure the distances. If a disposal point is very close to the centroid, some judgement will be needed to decide on a 'typical distance' for a point in the area from this disposal point.

Whatever their size, the collection areas should each be entirely within the boundaries of one of the district authorities in the county. The purpose of this restriction is to enable the program to indicate the total costs incurred by each of the district authorities, in delivering the refuse to the disposal point specified by the county. This information will be significant when deciding on possible payments from the county to the districts for 'unreasonable' travel distances, which may be made under the Control of Pollution Act. The costs directly to the county, due to the operation of disposal facilities and the use of transfer vehicles,

are also shown separately in the output. All costs are shown both as totals for each time period, and as an average annual cost in each period.

When dealing with problems of this kind, involving expenditure spread through time, it is usual to regard costs in the future as being less important than those in the present, and to discount them at some specified rate of interest to obtain the "net present cost" of a scheme. This is the sum which would have to be invested now, at the given rate of interest, to pay for the whole scheme. For schemes in the public sector, it is normal practice to use the Treasury test discount rate, currently 10% per annum. The program works on the basis of net present costs, and all results are presented in this form. In the input, it is only necessary to specify current costs, together with the rate of discount to be used.

It was thought desirable that the final output of the program should be easily readable, without knowledge of the program or the data preparation, and accordingly the collection and disposal points can be denoted by names of up to 32 characters in the output. Considering the task of data preparation and input, however, it would clearly be very laborious to prepare data on a large number of routes from point to point if the full name were the only way to specify a point. Also, with such long names there would inevitably be coding errors, differences in spacing, etc. which would result in the program failing to recognise a name, and again correction would be very laborious. For these reasons, points are

represented in the input by a code, consisting of four characters. Any characters may be used, except that a completely blank code, and any code which is the same as a data separator or command, must not be used. (Since all separators and commands begin with an asterisk, it is recommended that no code should begin with an asterisk, to avoid any confusion).

B.3 How to use the program

The program requires two input streams, one for 'commands' and one for 'data'. It always produces a 'log' output stream, listing the commands processed, error messages, etc., and may (depending on the commands used) produce a 'network' output stream containing the details of the flow networks and their costs. When the program is used interactively, the terminal provides the command input and log output streams.

In this case, echoing of commands to the log output should be suppressed (see section B.6), and the data input will probably be provided from a previously stored file. If the program is run as a background job (i.e. not interactively) both data and commands may, if required, be provided from the same input stream (the data preceding the commands); separate sources may still be used if preferred.

The program as given occupied 35648 words of core on the Aston 1904S, using the XFIV compiler. The time taken for a run depends almost entirely on the number of optimisations involved - other operations require only a few seconds of milltime at most. The time taken for

the first optimisation was typically about 60 seconds for the West Midlands data - obviously this timing is entirely dependent on the amount of data involved. Subsequent optimisations will usually be much quicker (unless very extensive changes to the available facilities have been made), since the solution procedure starts from the previously found flow system.

A number of error messages may be produced, most of which are self-explanatory. They are nearly all due to incorrect data, and will cause termination of the run. An incorrect command will give a message, but continue the run. Some FORTRAN execution errors may also be produced by incorrect data, e.g. if a non-numeric character is included in a numeric field. There are some messages indicating internal program errors, which begin with SYSTEM ERROR. These should never occur.

B.4 Program commands

When the program is started, it reads the data given, and sends the comments (See section B.5) to the log output. It then expects a command. Commands consist of an asterisk followed by three letters, which must be typed in the first four columns of an input line, with nothing else on the line. The commands which will be recognised at present are as follows:-

*EXC (exclude). This starts the operation of excluding disposal points from the available set. The codes for the points to be excluded are expected to follow the command, one per line, in the first four columns. When all the required points have been entered, any

command may be typed.

*INC (include). This restores points, previously removed using *EXC, to the available set. It is followed by the codes for the points, as for *EXC.

*LIS (list). This gives a list, on the log output, of the codes for all disposal points, and the corresponding full names. It is intended as an aid for the memory when using *EXC and *INC on-line from a terminal.

*RUN. This carries out the computation to find a minimum-cost flow system with the currently available disposal points.

*COS (cost). This prints the overall total cost, and the annual cost in each period, on the log output. It is useful for cost comparison of alternative arrangements, when using a terminal. It is only valid when the flow system has been optimised (by using *RUN), and no change has since been made in the available set of disposal points (with *EXC and/or *INC). If these conditions are not met, the message OUTPUT INVALID IN THIS CONTEXT will be given.

*FLO (flows). This prints the complete flow system, and costs, on the lineprinter (network output stream). The same restriction on the validity of its use applies as for *COS, and the same error message will result if it is violated.

*FIN (finish). This ends the program run.

B.5. Data format

The format for the data is designed to be suitable for

card input, but it is anticipated that in practice it will be found more convenient to maintain a file containing the data than to alter and re-input the cards. The current data for the West Midlands work is shown in Appendix D. The data falls into five main sections.

The first two lines of the data give the various parameters of the problem. The format of these lines is as follows:-

- | | | |
|---------|----------------|---|
| Line 1. | Column 1. | Number of time periods (an integer, not 0). |
| | Columns 2-3. | Number of district authorities (for cost analysis) (an integer between 1 and 50 inclusive). |
| | Columns 4-8. | Percentage annual discount rate for costs. |
| | Columns 9-13. | Percentage annual growth in refuse arisings. |
| | Columns 14-18. | Percentage annual growth in the cost of operating transfer stations. |
| | Columns 19-23. | Cost in pence per tonne-minute of transport by refuse collection vehicles. |
| | Columns 24-28. | Percentage annual growth in this cost. |
| | Columns 29-33. | Cost in pence per tonne-minute of transport by bulk vehicles (from a transfer station). |

- Columns 34-38. Percentage annual growth in this cost.
- Columns 39-43. Percentage annual growth in the cost of operating incinerator plants.
- Columns 44-48. Percentage annual growth in the cost of operating landfill sites.
- Line 2. Columns 1-5. Length in years of the first time period.
- Columns 6-10. Length in years of the second time period,
(and so on for as many periods as required - 9 at most).

Except for the first two numbers, which must obviously be integers, any of these numbers may include a decimal point, with figures before or after it as required. They should all be entered right-justified in their fields (i.e. with no blank spaces following them). The growth rates may be negative, zero, or positive; the costs may be zero or positive, but not negative; the lengths of periods must be greater than zero.

After these two lines, there may be up to 60 lines of comments. The first 72 characters of each line will be stored, and output at the beginning of the log output, and of each flow network output to the network output stream. No line may begin with four characters which constitute a data separator; since these all begin with an asterisk, it is suggested that no comment should begin with an asterisk. (The data separators are *COL, *TRA,

*INC, *TIP, *ROU, *DIS).

The comments are followed by the data on points, the third main part of the data. First the collection points are entered. The start of this section is signalled by the separator *COL, which must occupy the first four columns on an otherwise empty line. This is followed by the data on each collection point in turn. Two lines are required per point. The first line consists of the four - character code which will denote the point (this may consist of any four characters except four blanks, or a string corresponding to any data separator or command), followed by a space, and then the full name which will denote this point on output (which may contain up to 32 characters, with no restrictions). The second line contains, in columns 1-2, the number of the district in which this collection area falls, and in columns 3-7, the arisings in the area per annum, in hundreds of tonnes. The first number must be an integer, the second need not be; both should be right-justified as before. For the purpose of indicating the district in which each collection area falls, the districts must be numbered consecutively from 1.

After the collection points, data on the transfer stations, if any, must be entered. If there are transfer stations, the separator *TRA must precede the data on them. The first line for each station gives the code and name, as for collection areas; the second line contains five numbers. Columns 1-5 contain the minimum throughput per year, and columns 6-10 the maximum, in hundreds of tonnes.

(It is useful to be able to specify a minimum as well as a maximum, since it will be unacceptable to run a plant far below its capacity; for a projected plant, the minimum can be made zero, and the maximum some very large number, to ascertain by using the program what flow passes through the station, and so gain an indication of how large it should be, if initial cost is not important). Columns 11-15 contain the cost, in pence per tonne, associated with processing the refuse at this station. This should only be used to represent that part of the cost which actually varies with the throughput, which will be a small part of the total. Columns 16-17 and 18-19 contain the numbers of the time periods in which the station opens and closes respectively. These may be left blank or entered as zero, in which case the opening period will be taken as period 1, and the closing period as the last period considered (i.e. the station is open throughout the planning period). Note that these period numbers are inclusive, i.e. an opening period of 2 and closing of 3 means that the station is open in periods 2 and 3.

Next the data on incinerators (if any) is entered, preceded by *INC. The form of the data for each incinerator is exactly the same as for transfer stations - the code and name on the first line, and the minimum and maximum throughputs, cost and opening and closing periods on the second. It should be noted that other types of plant, e.g. composting or pyrolysis, could be included here, since this heading indicates in annual terms, rather than the total capacity over all time, as for landfill sites. In the West Midlands data, one large private landfill site

used by the county on a contract basis has been included here, as the limitations on its use are of this form.

The separator *TIP indicates the beginning of data on landfill sites. The first line of data on each site gives the code and name as before. The second gives the capacity of the site (in hundreds of tonnes) in columns 1-5, the cost per tonne in columns 6-10, and the opening and closing time periods in columns 11-12 and 13-14 respectively. The interpretation of the closing time period here differs slightly from that for other types of point. If a non-zero time period is specified, this will be interpreted as indicating that the site must be filled to the given capacity by the end of the period; if this field is zero or blank, the site will be allowed to have some spare capacity remaining at the end of the planning period.

After the data on all points comes the data on routes between points, preceded by the separator *ROU. Each line of the data begins either with the code of the point from which these routes start, or four spaces, indicating that this is a continuation of the preceding line, starting from the same point. Column 5 is blank, and then there are six groups of ten columns each. The first four columns of a group contain the code of the point to which this route leads; the following six contain the time, in minutes, for a round trip along this route. If the code field is blank, the group is ignored. Any route not coded will be assumed to be impossible to use. It is therefore important to ensure that all likely routes are included.

The final section of the data contains the names of the districts. This section starts with *DIS. Each line then contains the number of the district (in columns 1 and 2), a space, and the name of the district (which may have up to 28 characters). The numbers must be consecutive, starting from 1.

There are some overall restrictions on the data. There must always be at least one disposal and one collection point (a disposal point here means an incinerator or landfill site), and there must not be more than 150 points in all. Each collection area and transfer station must have at least one, and not more than 50, routes leading from it. Violating these restrictions will result in an error message and the termination of the run. It is also possible to produce a problem which is too large for the central part of the program, the optimisation routine. This will result in the more cryptic message TOO MANY NODES or TOO MANY ARCS, which refers to the general mathematical problem dealt with by this routine. These can be cured by reducing the number of points, or in the latter case the number of routes.

B.6 Technical details of the program

The basic mathematical form of the problem being dealt with here is a 'transshipment problem' with the addition of lower bounds. A general program for the transshipment problem exists for 1900 series computers, and this problem can also be solved using linear programming, for which a general program is available for most machines. These general-purpose programs, however, use coded input and output which is not readily legible, and, particularly

for linear programming codes, there would be a great deal of repetitive data to be input, and a lot of trivial arithmetic would be required to produce or alter it. The first approach tried was to write a pre-processor to generate data in a suitable format. This did not solve the output legibility problem, and since published algorithms for this type of problem are readily available, it was decided to produce a complete system to input, solve and output the problem. This would (a) have input and output in convenient forms, (b) be easier to write than interfaces with general-purpose programs, and more readily portable, and (c) might even be more efficient, since it could be designed for the problem in hand. (In fact the present program is a good deal faster than the ICL transshipment package, but requires much more store, and could not handle such large problems - though it has proved quite adequate for present needs).

The algorithm used in this program is a very general one for problems involving network flows, the 'out-of-kilter' algorithm of Ford and Fulkerson (1962). It works on the basis of a circulation in the network. The network contains nodes, each of which correspond to a particular point in a particular time period (except for landfill sites, where one node represents the site in all periods), and arcs which join nodes representing different points in the same time period. To complete the circulation, one node not corresponding to any user-specified point is introduced, from which all arisings flow, and to which all disposal returns. (It might seem simpler to consider each time period separately for optimisation. However, this would tend to result in the early filling-up of well-

placed landfill sites, and rising costs in later time periods. To optimise the way landfill sites are used during the planning period, it is necessary to consider the problem as a whole).

A listing of the program is given in Appendix C. It is written in FORTRAN IV, conforming as far as possible to the ISO standard, so that it should be reasonably easy to transfer to a different machine. (Much of the development work was in fact carried out on a DEC PDP 11/40, and the program was then transferred to the 1904S without much difficulty). The following points should be noted if such a transfer is attempted.

There is one deviation from the standard, in that both the main routine and the subroutine NEWDAT contain DATA statements which initialise complete arrays, by specifying only the array name. This is a widely available extension to the standard; if it is not available on a particular machine, the array name must be replaced by a list of all the array elements in ascending order.

The BLOCK DATA subprogram sets up some parameters which depend on the particular machine being used, including the input and output unit numbers, the largest integer represented in the machine, and a flag ONLINE, which indicates whether or not the program will be used interactively. (The effect of setting this `.TRUE.` is that echoing of the command input stream to the log output stream is suppressed - this would be irritating when both streams correspond to the teletype). The parameter RMAXLG is no longer used.

Though the program uses input and output of characters a great deal, the only actual manipulation of characters is done by the function LISTEL, which scans a list of four-character codes to find one corresponding to a given four characters. The version given here uses the 1900 series library routine COMP, needed because an attempt to compare characters directly in 1900's may cause an overflow. On many machines a direct comparison (IF(A.E Q.B(LISTEL)) GOTO3) will be satisfactory; if this is not the case, and no library routine for character comparison is available, it will be necessary to code this function in assembler. There should be no difficulty with the storage of characters, at four characters per real number; if this is too much on any machine, the arrays and variables which are used to contain characters could all be declared as COMPLEX, thus doubling the space available.

The main routine contains one feature added for convenience in the 1900 version, which will probably be of no use on other machines. The call to the library routine SSWTCH tests 'sense switch' 1 of the program, which is set by the GEORGE macro to indicate whether or not the program is being run on-line (this overrides the BLOCK DATA specification of ONLINE).

There may be some difficulty in implementing this program on smaller machines, because of its storage requirements. It would be easy to overlay the major routines (NEWDAT, GROWTH and SETARC as a unit, KILTER, OUTPUT and UNFEAS each as separate units), but this would

save only a few thousand words - most of the space is occupied by arrays. To obtain substantial reductions, it would be necessary either to use a scratch file to hold, say, the contents of the common block /FILE/, and read them when needed, or to reduce the size of problem which can be handled. Reducing the maximum number of arcs and nodes would save 9 words per arc and 8 words per node; reducing the maxima from their present 2000 and 300 to 1500 and 200 would thus save over 5000 words. (Conversely, it would be possible to increase the size of the relevant arrays, if a very large problem were being tackled and storage was not in short supply).


```

REAL COMTAB(7), CNAME(18,60), NAME(8,150), DNAME(7,50), COTAB(150),
1  LENP(9)
LOGICAL ONLINE, LARG, VALOUT
INTEGER COST(2000), LOWB(2000), UPB(2000), FROM(2000), TO(2000),
1  FLOW(2000), ABAR(2000), SETUB(2000), SETLB(2000), IDIS(150), PER(300),
2  POINT(300)
COMMON/PARAMS/ ONLINE, MAXINT, RMAXLG, IOUCOM, IOUDAT, IOULOG, IOUNET
COMMON/PROBLM/NN, NA, NP, NDIS, NCOM, FROM, TO, ABAR, LOWB, UPB, FLOW
COMMON /FILE/ CNAME, NAME, DNAME, COTAB, NPERS, LENP, IDIS, PER,
1  POINT, COST, SETUB, SETLB
DATA COMTAB/4H*EXC, 4H*INC, 4H*RUN, 4H*COS, 4H*FLO, 4H*FIN, 4H*LIS/
DATA VALOUT/.FALSE./

C
C   FOR 1900 VERSION ONLY
C   TEST FLAG FOR MOP OPERATION
C   CALL SSWTCH(1,I)
C   ONLINE=I.EQ.1

C
C   INPUT DATA - STOP IF ERROR
C   CALL NEWDAT(LARG)
6  IF(LARG) STOP 1

C
C   READ NEXT COMMAND, ECHO IF NECESSARY
1  READ(IOUCOM,3) COMAND
3  FORMAT(A4)
   IF(.NOT.ONLINE) WRITE(IOULOG,4) COMAND
4  FORMAT(1X,A4)

C
C   IDENTIFY COMMAND
I=LISTEL(COMAND,COMTAB,7)
IF(I.NE.0) GO TO (10,11,20,30,31,40,50), I
C   I=0, COMMAND NOT IN TABLE
WRITE(IOULOG,9)
9  FORMAT(21H UNRECOGNISED COMMAND)
   GO TO 1

C
C   EXCLUDE POINTS
10 ASSIGN 16 TO LABEL
   GO TO 18

C
C   RE-INCLUDE POINTS
11 ASSIGN 17 TO LABEL
18 VALOUT=.FALSE.

C
C   READ CODE OF POINT TO EXCLUDE/INCLUDE
12 READ(IOUCOM,13) CODE
13 FORMAT(A4)
   IF(.NOT.ONLINE) WRITE(IOULOG,14) CODE
14 FORMAT(1X,A4)

C   IDENTIFY POINT
I=LISTEL(CODE,COTAB,NP)
IF(I.EQ.0) GO TO 110
IF(IDIS(I).GT.0) GO TO 112
C   TEST EACH ARC - IS IT FROM THIS POINT?
DO 15 J=1,NA
  K=FROM(J)
  IF(I.NE.POINT(K)) GO TO 15
  GO TO LABEL,(16,17)

C   INTRODUCE ARC
17 LOWB(J)=SETLB(J)
  UPB(J)=SETUB(J)
  GO TO 15

C   REMOVE ARC
16 LOWB(J)=0
  UPB(J)=0
15 CONTINUE
   GO TO 12

C   EXIT FROM INCLUDE/EXCLUDE
110 I=LISTEL(CODE,COMTAB,7)
   IF(I.NE.0) GO TO (10,11,20,30,31,40,50), I
C   INCLUDE/EXCLUDE ERROR MESSAGES

```

```
WRITE(IOULOG,111)
111 FORMAT(18H UNRECOGNISED CODE )
GO TO 12
112 WRITE(IOULOG,113)
113 FORMAT(41H YOU CANNOT EXCLUDE A COLLECTION CENTROID )
GO TO 12
C
C RUN OPTIMISING ROUTINE
20 CALL KILTER(IARG)
25 IF(IARG) 22,29,21
C FEASIBLE SOLUTION FOUND
29 VALOUT=.TRUE.
GO TO 1
C
C NON-FEASIBLE
21 VALOUT=.FALSE.
CALL UNFEAS(IARG)
GO TO 1
C
C SYSTEM ERROR
22 IARG=-IARG
WRITE(IOULOG,23) IARG
23 FORMAT(22H SYSTEM ERROR - KILTER,12)
STOP 23
C
C OUTPUT COSTS ONLY (TO IOULOG)
30 LARG=.FALSE.
GO TO 32
C
C FULL OUTPUT (TO IOUNET)
31 LARG=.TRUE.
32 IF(.NOT.VALOUT) GO TO 38
CALL OUTPUT(LARG)
GO TO 1
C
38 WRITE(IOULOG,39)
39 FORMAT(31H OUTPUT INVALID IN THIS CONTEXT )
GO TO 1
C
C FINISH
40 STOP
C
C LIST CODES AND NAMES
S0 DO S2 K=1,NP
IF(IDIS(K).LE.0) GO TO S3
S2 CONTINUE
S3 WRITE(IOULOG,S1) (COTAB(I),(NAME(J,I),J=1,8),I=K,NP)
S1 FORMAT(1X,A4,1X,8A4)
GO TO 1
C
END
```

```

BLOCK DATA
REAL NAME(8,150),CNAME(18,60),DNAME(7,50),COTAB(150),LENP(9)
INTEGER IDIS(150),PER(300),POINT(300),COST(2000),SETUB(2000),
1  SETLB(2000),FROM(2000),TO(2000),ABAR(2000),LOWB(2000),UPB(2000),
2  FLOW(2000)
LOGICAL ONLINE
COMMON /PROBLM/ NN,NA,NP,NOIS,NCOM,FROM,TO,ABAR,LOWB,UPB,FLOW
COMMON /PARAMS/ ONLINE,MAXINT,RMAXLG,IOUCOM,IOUDAT,IOULOG,IOUNET
COMMON /FILE/ CNAME,NAME,DNAME,COTAB,NPERS,LENP,IDIS,PER,POINT,
1  COST,SETUB,SETLB
DATA IOUCOM,IOUDAT,IOULOG,IOUNET/1,2,3,4/
DATA ONLINE,MAXINT,RMAXLG/.FALSE.,8388607,1.E-70/

C
C /PROBLM/ -
C NP- NO. OF POINTS USED
C NOIS - NO. OF DISTRICTS USED
C NCOM - NO. OF LINES OF COMMENTS
C FOR DETAILS OF OTHER CONTENTS OF THIS BLOCK, SEE COMMENTS IN
C SUBROUTINE KILTER
C
C /PARAMS/ -
C ONLINE - TRUE IF IOULOG AND IOUCOM ARE PHYSICALLY THE SAME DEVICE
C (I.E.USUALLY THE TERMINAL) - SUPPRESSES ECHOING
C MAXINT - LARGEST INTEGER ON THE MACHINE
C RMAXLG - SMALL REAL NO. SUCH THAT 1/ALOG(1+RMAXLG) WON'T OVERFLOW
C IOUCOM,IOUDAT,IOULOG,IOUNET - FORTRAN I/O UNIT NOS. FOR COMMANDS,DATA,
C LOG OUTPUT,FLOW NETWORK OUTPUT RESPECTIVELY
C
C /FILE/ -
C CNAME - TEXT OF COMMENTS
C NAME( ,I) - NAME OF POINT I
C DNAME( ,J) - NAME OF DISTRICT J
C COTAB(I) - CODE FOR POINT I
C NPERS - NO. OF PERIODS USED
C LENP(I) - LENGTH OF PERIOD I
C IDIS(J) - DISTRICT NO. OF POINT I, IF I IS A COLLECTION CENTROID
C 0 IF I IS A TRANSFER STATION
C -1 IF I IS AN INCINERATOR
C -2 IF I IS A LANDFILL SITE
C PER(J) - PERIOD NO. OF NODE J
C POINT(J) - POINT NO. OF NODE J
C COST(I) - COST PER UNIT FLOW IN ARC I (AS INPUT)
C SETUB(I) - MAX. FLOW ALLOWED IN ARC I (AS INPUT)
C SETLB(I) - MIN. FLOW ALLOWED IN ARC I (AS INPUT)
C
C NOTE THAT ABAR IN /PROBLM/ IS ALTERED BY SUBROUTINE KILTER
C AND LOWB,UPB ARE ZEROED BY USING MEXC
C
END

```

```

SUBROUTINE NEWDAT(LARG)
C
C THIS ROUTINE READS IN THE DATA AND SETS UP THE PROBLEM
C BY EXPANDING THE INPUT POINTS AND ROUTES INTO A MULTI-
C PERIOD NETWORK OF NODES AND ARCS
C
REAL NAME(8,150),CNAME(18,60),DNAME(7,50),COMTAB(7),LENP(9),
1 COTAB(150),AFAC(9),CXFAC(9),CCUFAC(9),CTUFAC(9),MIN,MAX,TOC(6),
2 TIME(6),LTIM(50),CIFAC(9),CTFAC(9)
INTEGER OPEN(150),SHUT(150),IDIS(150),PER(300),POINT(300),NODE(9,
1 150),COST(2000),LOWB(2000),UPB(2000),FROM(2000),TO(2000),PTO(50),
2 FLOW(2000),ABAR(2000),SETUB(2000),SETLB(2000)
LOGICAL LARG,ONLINE,OVER,LINKED(150)
COMMON /PARAMS/ ONLINE,MAXINT,RMAXLG,IOUCOM,IOUDAT,IOULOG,IOUNET
COMMON /PROBLEM/ NN,NA,NP,NDIS,NCOM,FROM,TO,ABAR,LOWB,UPB,FLOW
COMMON /FILE/ CNAME,NAME,DNAME,COTAB,NPERS,LENP,IDIS,PER,POINT,
1 COST,SETUB,SETLB
COMMON LTIM,TOCO,TIME,PTO,LINKED,NODE,OPEN,SHUT
DATA COMTAB/4H=COL,4H=TRA,4H=INC,4H=TIP,4H=ROU,4H=DIS,4H /
NINT(X)=INT(X+0.5)
NINL(X)=NINT(X*LENP(J))
C
NN=1
NA=0
POINT(1)=0
PER(1)=0
C
C NODE 1 IS USED BY SYSTEM AS SOURCE OF ALL ARISING
C AND SINK OF ALL FINAL DISPOSAL, TO FORM A COMPLETE CIRCULATION
C
READ(IOUDAT,5) NPERS,NDIS,DRATE,GA,GCX,CCU,GCCU,CTU,GCTU,
1 GCI,GCT
5 FORMAT(I1,I2,9F5.0)
IF(NPERS.LE.0) GO TO 9001
NPERS IS NO.OF PERIODS TO CONSIDER
C
C NDIS - NO. OF DISTRICTS
C
C DRATE - PERCENT/ANNUM DISCOUNT RATE FOR ALL COSTS
C
C GA - PERCENT/ANNUM GROWTH IN REFUSE ARISING
C
C GCX - PERCENT/ANNUM GROWTH IN COST OF TRANSFER STATION OPERATION
C
C CCU - COST PER MINUTE OF COLLECTION VEHICLES (PENNY)
C
C GCCU - PERCENT/ANNUM GROWTH IN CCU
C
C CTU - COST PER MINUTE OF TRANSFER VEHICLES (PENNY)
C
C GCTU - PERCENT/ANNUM GROWTH IN CTU
C
C GCI - PERCENT/ANNUM GROWTH IN INCINERATION COSTS
C
C GCT - PERCENT/ANNUM GROWTH IN LANDFILL COSTS
C
READ(IOUDAT,2) (LENP(I),I=1,NPERS)
2 FORMAT(9F5.0)
LENP(I) - LENGTH OF PERIOD I (YEARS)
C
DO 6 I=1,NPERS
IF(LENP(I).LE.0) GO TO 9001
6 CONTINUE
IF(NDIS.LE.0.OR.NDIS.GT.50) GO TO 9002
C
C EVALUATE GROWTH FACTORS FOR ARISING AND COSTS
CALL GROWTH(GA,0.0,LENP,AFAC,NPERS)
CALL GROWTH(GCX,DRATE,LENP,CXFAC,NPERS)
CALL GROWTH(GCCU,DRATE,LENP,CCUFAC,NPERS)
CALL GROWTH(GCTU,DRATE,LENP,CTUFAC,NPERS)
CALL GROWTH(GCI,DRATE,LENP,CIFAC,NPERS)
CALL GROWTH(GCT,DRATE,LENP,CTFAC,NPERS)
DO 1 I=1,NPERS
CXFAC(I)=CXFAC(I)/LENP(I)
CIFAC(I)=CIFAC(I)/LENP(I)
CTFAC(I)=CTFAC(I)/LENP(I)
CCUFAC(I)=CCU*CCUFAC(I)/LENP(I)
CTUFAC(I)=CTU*CTUFAC(I)/LENP(I)
1 CONTINUE
C
C READ AND LOG COMMENTS
DO 7 NCOM=1,60

```

```

      READ( IOU DAT, 8 ) ( CNAME( I, NCOM ), I=1, 18 )
8  FORMAT( 18A4 )
      I=LISTEL( CNAME( 1, NCOM ), COMTAB, 6 )
      IF( I.NE.8 ) GO TO 8
      WRITE( IOU LOG, 100 ) ( CNAME( I, NCOM ), I=1, 18 )
100 FORMAT( 1X, 18A4 )
      7 CONTINUE
      NCOM=61
      READ( IOU DAT, 8 ) COMAND
      I=LISTEL( COMAND, COMTAB, 6 )
      IF( I.EQ.8 ) GO TO 9004
      9 IF( I.NE.1 ) GO TO 9005
      NCOM=NCOM-1
      LI=1
C
C  LOOP TO READ DATA ON EACH POINT
C  DO 10 NP=1, 150
C
C  READ CODE AND NAME, CHECK FOR COMMANDS
12 READ( IOU DAT, 101 ) COTAB( NP ), ( NAME( I, NP ), I=1, 8 )
101 FORMAT( A4, 1X, 8A4 )
      I=LISTEL( COTAB( NP ), COMTAB, 7 )
      IF( I.EQ.8 ) GO TO 55
      IF( I.EQ.7 ) GO TO 9015
      IF( I.LT.LI.OR.I.EQ.6 ) GO TO 9006
      IF( I.EQ.5 ) GO TO 62
      LI=I
      GO TO 12
C
C  NOT A COMMAND, CHECK CODE NOT USED BEFORE, GO TO APPROPRIATE
C  SECTION ( LI = 1, 2, 3, 4 IF LAST COMMAND WAS #COL, #TRA, #INC, #TIP
C  RESPECTIVELY )
55 I=LISTEL( COTAB( NP ), COMTAB, NP )
      IF( I.NE.NP ) GO TO 9015
      GO TO ( 31, 32, 33, 34 ), LI
C
C  COLLECTION CENTROIDS
C
31 READ( IOU DAT, 102 ) IDIS( NP ), QTY
102 FORMAT( I2, F5.0 )
      IF( IDIS( NP ).LE.0.OR.IDIS( NP ).GT.NDIS ) GO TO 9016
      OPEN( NP )=1
      SHUT( NP )=NPERS
      DO 11 J=1, NPERS
      NN=NN+1
      IF( NN.GT.300 ) GO TO 9007
      PER( NN )=J
      POINT( NN )=NP
      NODE( J, NP )=NN
      IA=NINT( AFAC( J ) * QTY )
      CALL SETARC( 1, NN, 0, IA, IA, OVER )
      IF( OVER ) GO TO 9008
11 CONTINUE
      GO TO 10
C
C  TRANSFER STATIONS
C
32 READ( IOU DAT, 103 ) MIN, MAX, CSTIN, IO, IS
103 FORMAT( 3F5.0, 2I2 )
      IF( IO.EQ.0 ) IO=1
      IF( IS.EQ.0.OR.IS.GT.NPERS ) IS=NPERS
      OPEN( NP )=IO
      SHUT( NP )=IS
      IDIS( NP )=0
      IF( IO.GT.IS ) GO TO 10
      DO 13 J=IO, IS
C
C  2 NODES MUST BE CREATED FOR EACH TRANSFER STATION IN EACH
C  PERIOD - INPUT AND OUTPUT OF STATION RESPECTIVELY
      NN=NN+2
      NN1=NN-1
      IF( NN.GT.300 ) GO TO 9007

```



```

      PER(NN)=J
      PER(NN1)=J
      POINT(NN)=NP
      POINT(NNL)=NP
      NODE(J,NR)=NN1
      CALL SETARC(NN1,NN,NINT(CSTIN*CXFAC(J)),NINLJ(MIN),NINLJ(MAX),
1 OVER)
      IF(OVER) GO TO 9008
13 CONTINUE
      GO TO 10
C
C
C      INCINERATORS
33 READ( IOUOAT, 104) MIN,MAX,CSTIN, IO, IS
104 FORMAT( 3FS,0,2I2)
      IF( IO.EQ.0) IO=1
      IF( IS.EQ.0.OR.IS.GT.NPERS) IS=NPERS
      OPEN(NP)=IO
      SHUT(NP)=IS
      IDIS(NR)=-1
      IF( IO.GT.IS) GO TO 10
      DO 15 J=IO,IS
      NN=NN+1
      IF(NN.GT.300) GO TO 9007
      PER(NN)=J
      POINT(NN)=NP
      NODE(J,NP)=NN
      CALL SETARC(NN,1,NINT(CSTIN*CFAC(J)),NINLJ(MIN),NINLJ(MAX),OVER)
      IF(OVER) GO TO 9008
15 CONTINUE
      GO TO 10
C
C
C      LANDFILL SITES
34 READ( IOUDAT, 105) QTY,CSTIN, IO, IS
105 FORMAT( 2FS,0,2I2)
      IF( IO.EQ.0) IO=1
      IQ=NINT(QTY)
      IF( IS.GT.0.AND.IS.LE.NPERS) GO TO 17
      IS=NPERS
      LB=0
      GO TO 18
17 LB=IQ
18 OPEN(NP)=IO
      SHUT(NP)=IS
      IDIS(NP)=-2
      IF( IO.GT.IS) GO TO 10
     >NNL=NN+IS-IO+2
      DO 16 J=IO,IS
      NN=NN+1
      IF(NN.GT.300) GO TO 9007
      PER(NN)=J
      POINT(NN)=NP
      NODE(J,NP)=NN
      CALL SETARC(NN>NNL,NINT(CSTIN*CTFAC(J)),0,IQ,OVER)
      IF(OVER) GO TO 9008
16 CONTINUE
     >NNL>NNL
      IF(NN.GT.300) GO TO 9007
      PER(NN)=0
      POINT(NN)=NP
      CALL SETARC(NN,1,0,LB,IQ,OVER)
      IF(OVER) GO TO 9008
C
10 CONTINUE
      NP=151
      READ( IOUDAT, 101) COMAND
      I=LISTEL( COMAND,COMTAB,6)
      IF( I.NE.S) GO TO 9006
C
C      ROUTES BETWEEN POINTS

```

```

C
62 LASTI=0
   NP=NP-1
   DO 63 I=1,NP
   LINKED(I)=.FALSE.
63 CONTINUE
   ASSIGN 26 TO LABEL
C
C   READ NEXT LINE, CHECK FOR COMMAND OR BLANK (REPEAT LINE)
20 READ(10, DAT, 21) FROMCO, ( TOCO(J), TIME(J), J=1,6)
21 FORMAT(A4, 1X, 6(A4, F6.0))
   I=LISTEL(FROMCO, CONTAB, 7)
   IF(I.EQ.0) GO TO 29
   IF(I.EQ.7) IF(LASTI) 9013, 9013, 25
   IF(I.NE.6) GO TO 9005
   IF(LASTI.EQ.0) GO TO 9013
   ASSIGN 59 TO LABEL
   GO TO 120
C
C   NEW SOURCE CODE
29 I=LISTEL(FROMCO, COTAB, NP)
   IF(I.EQ.0) GO TO 9009
   IF(I.EQ.LASTI) GO TO 25
   IF(IDIS(I).LT.0) GO TO 9011
   IF(LASTI.EQ.0) GO TO 25
   IF(LINKED(I)) GO TO 9014
C
C   CREATE ARCS FROM LASTI
C   (LAST LINE READ HAS NEW SOURCE CODE, SO THERE ARE NO MORE
C   ARCS FROM POINT LASTI)
C
120 IO=OPEN(LASTI)
   IS=SHUT(LASTI)
   DO 22 J=IO, IS
   IFR=NODE(J, LASTI)
   IF(IDIS(LASTI).EQ.0) GO TO 24
   FAC=CCUFAC(J)
   GO TO 28
24 FAC=CTUFAC(J)
   IFR=IFR+1
28 DO 23 K=1, NR
   L=PTO(K)
   IF(OPEN(L).GT.J.OR.SHUT(L).LT.J) GO TO 23
   CALL SETARC(IFR, NODE(J, L), NINT(LTIM(K)*FAC), 0, MAXINT, OVER)
   IF(OVER) GO TO 9008
23 CONTINUE
22 CONTINUE
   GO TO LABEL, (26, 59)
C
C   DECODE DATA INTO PTO, LTIM
C
26 LASTI=I
   LINKED(I)=.TRUE.
   NR=0
25 DO 27 J=1, 6
C   SCAN INPUT LINE, IGNORE BLANK CODES
   K=LISTEL(TOCO(J), CONTAB(7), 1)
   IF(K.EQ.1) GO TO 27
   K=LISTEL(TOCO(J), COTAB, NP)
   IF(K.EQ.0) GO TO 9010
   IF(K.EQ.LASTI) GO TO 9012
   NR=NR+1
   IF(NR.GT.50) GO TO 9017
   PTO(NR)=K
   LTIM(NR)=TIME(J)
27 CONTINUE
   GO TO 20
C
C   *OIS READ - CHECK FOR MISSING ROUTES
C
59 DO 81 I=1, NP
   IF(IDIS(I).LT.0) GO TO 82

```

```

      IF(.NOT.LINKED(I)) GO TO 9018
    81 CONTINUE
  C
  C   READ DISTRICT NAMES
    82 DO 3 I=1,NDIS
      READ(IOUDAT,4) J,(DNAME(K,I),K=1,7)
      4 FORMAT(I2,1X,7A4)
      IF(J.NE.I) GO TO 9003
    3 CONTINUE
  C
  C   SET UP FLOW, AND FILE COPIES OF COST,UPB,LOWB
    DO 80 I=1,NA
      FLOW(I)=0
      COST(I)=ABAR(I)
      SETUB(I)=UPB(I)
      SETLB(I)=LOWB(I)
    80 CONTINUE
  C
  C   NORMAL EXIT
    LARG=.FALSE.
    90 RETURN
  C
  C   ERROR MESSAGES
  C
    9001 WRITE(IOULOG,9101)
    9101 FORMAT(17H ERROR IN PERIODS )
      GO TO 9999
    9002 WRITE(IOULOG,9102)
    9102 FORMAT(26H WRONG NUMBER OF DISTRICTS )
      GO TO 9999
    9003 WRITE(IOULOG,9103)
    9103 FORMAT(26H DISTRICT WRONGLY NUMBERED )
      GO TO 9999
    9004 WRITE(IOULOG,9104)
    9104 FORMAT(18H TOO MANY COMMENTS )
      GO TO 9999
    9005 WRITE(IOULOG,9105) COMTAB(I)
    9105 FORMAT(24H COMMAND OUT OF ORDER - ,A4)
      GO TO 9999
    9006 WRITE(IOULOG,9106)
    9106 FORMAT(16H TOO MANY POINTS )
      GO TO 9999
    9007 WRITE(IOULOG,9107)
    9107 FORMAT(15H TOO MANY NODES )
      GO TO 9999
    9008 WRITE(IOULOG,9108)
    9108 FORMAT(14H TOO MANY ARCS )
      GO TO 9999
    9009 WRITE(IOULOG,9109) FROMCO
    9109 FORMAT(29H UNRECOGNISED SOURCE CODE - ,A4)
      GO TO 9999
    9010 WRITE(IOULOG,9110) COTAB(LASTI),TOCD(J)
    9110 FORMAT(33H UNRECOGNISED DESTINATION CODE - ,A4,4H....,A4)
      GO TO 9999
    9011 WRITE(IOULOG,9111) FROMCO
    9111 FORMAT(23H INVALID SOURCE CODE - ,A4)
      GO TO 9999
    9012 WRITE(IOULOG,9112) TOCD(J)
    9112 FORMAT( 24H SOURCE = DESTINATION - ,A4)
      GO TO 9999
    9013 WRITE(IOULOG,9113)
    9113 FORMAT(20H ROUTES OUT OF ORDER )
      GO TO 9999
    9014 WRITE(IOULOG,9114) FROMCO
    9114 FORMAT(24H REPEATED SOURCE CODE - ,A4)
      GO TO 9999
    9015 WRITE(IOULOG,9115) COTAB(I)
    9115 FORMAT(19H CODE DUPLICATED - ,A4)
      GO TO 9999
    9016 WRITE(IOULOG,9116) COTAB(NP)
    9116 FORMAT(26H INVALID DISTRICT NO. FOR ,A4)

```

```
GO TO 9999
9017 WRITE( IOULOG, 9117 ) COTAB( LASTI )
9117 FORMAT( 22H TOO MANY ROUTES FROM ,A4 )
GO TO 9999
9018 WRITE( IOULOG, 9118 ) COTAB( I )
9118 FORMAT( 16H NO ROUTES FROM ,A4 )
C
9999 LARG= .TRUE.
C ERROR EXIT
GO TO 90
END
```

```
      SUBROUTINE GROWTH(PCTG,PCTD,LENP,FAC,NPERS)
C
C   CALCULATE TIME FACTORS, FOR PCTG PERCENT COMPOUND GROWTH
C   AND PCTD PERCENT DISCOUNT
C
      REAL LENP(NPERS),FAC(NPERS)
      TEMP=(1.0+0.01*PCTG)/(1.0+0.01*PCTD)
      IF(ABS(TEMP-1.0).LT.1.0E-5) GO TO 4
      TAU=1.0/ALOG(TEMP)
      T1=0.0
      EXPT1=1.0
      DO 5 I=1,NPERS
      T2=T1+LENP(I)/TAU
      EXPT2=EXP(T2)
      FAC(I)=(EXPT2-EXPT1)*TAU
      T1=T2
      EXPT1=EXPT2
5     CONTINUE
      GO TO 1
C
4     DO 6 I=1,NPERS
      FAC(I)=LENP(I)
6     CONTINUE
C
1     RETURN
      END
```

```
FUNCTION LISTEL(A,B,N)
C
C LOCATION OF 4-CHARACTER TEXT A IN LIST B
C RETURNS 0 IF A NOT FOUND
C *** MACHINE DEPENDENT *** - THIS IS 1980 VERSION
DIMENSION B(N)
IF(N.LT.1) GO TO 2
DO 1 LISTEL=1,N
  I=4
  CALL COMP(I,A,1,B(LISTEL),1)
  IF(I.EQ.4) GO TO 3
1 CONTINUE
2 LISTEL=0
3 RETURN
END
```

```

SUBROUTINE SETARC(IF, IT, IC, IL, IU, OVER)
C
C TRIVIAL ROUTINE TO SET UP NEXT ARC OF PROBLEM FOR NEWOAT
C
C INTEGER FROM(2000), TO(2000), ABAR(2000), LOWB(2000), UPB(2000),
1 FLOW(2000)
C LOGICAL OVER
C COMMON /PROBLM/ NN, NA, NP, NDIS, NCOM, FROM, TO, ABAR, LOWB, UPB, FLOW
C
C NA=NA+1
C OVER=NA.GT.2000
C IF(OVER) GO TO 1
C
C FROM(NA)=IF
C TO(NA)=IT
C ABAR(NA)=IC
C LOWB(NA)=IL
C UPB(NA)=IU
C
1 RETURN
END

```

```

SUBROUTINE KILTER(IFEAS)
*****
FINDS A LEAST-COST CIRCULATION BY THE 'OUT-OF-KILTER' METHOD
FORD AND FULKERSON, 'FLOWS IN NETWORKS' CH.III PARA.11
*****

PRESET VARIABLES -
FROM(J) - NO. OF NODE AT START OF LINK J
TO(J) - NO. OF NODE AT END OF LINK J
LOWB(J) - MIN. FLOW ACCEPTABLE IN LINK J
UPB(J) - MAX. FLOW ACCEPTABLE IN LINK J
ABAR(J) - PSEUDO-COST OF LINK J (SEE F.AND F.)
FLOW(J) - FLOW RATE IN LINK J
NN - NUMBER OF NODES USED
NA - NUMBER OF LINKS (OR ARCS) USED
MAXINT - LARGEST INTEGER ON THIS MACHINE

WORK SPACES -
INDEX(X) - NO. OF FIRST LINK STARTING FROM NODE X
           (LINKS STARTING FROM SAME NODE MUST BE CONSECUTIVE)
INDTO(X) - NO. OF FIRST LINK ENDING AT NODE X
NEXL(J) - NO. OF NEXT LINK ENDING AT THE SAME NODE AS LINK J
          (THIS IS ZERO IF THERE ARE NO MORE)
LABEL(X) - IABS(LABEL(X)) IS NO. OF NODE FROM WHICH X WAS
          LABELLED, OR 0 IF X IS UNLABELLED
          + IF LABELLED FORWARD, - IF BACKWARD
          (SEE F.AND F.)
JREC(X) - NO. OF LINK ALONG WHICH X WAS LABELLED
EPS(X) - F. AND F.'S EPSILON LABEL FOR X
LABLIS(PIN) - STACK OF LABELLED NODES, REMOVED AS THE ARCS TO/FROM
             THEM ARE TRIED FOR LABELLING
PIN - STACK POINTER FOR LABLIS

ARGUMENT -
IFEAS RETURNS 0 IF OPTIMUM REACHED
OTHERWISE IFEAS CONTAINS THE NUMBER OF THE ARC WHERE INFEASIBILITY
WAS FOUND
OR -1,-2,-3 INDICATING ERRORS IN THE DATA SUPPLIED
*****

INTEGER FROM(2000), TO(2000), LOWB(2000), UPB(2000), ABAR(2000),
1 FLOW(2000), LABEL(300), EPS(300), JREC(300), LABLIS(300), INDEX(300),
2 INDTO(300), NEXL(2000), S, T, X, Y, TEMP, PIN, TARGET, EP, DELTA, EPS
LOGICAL ONLINE
COMMON /PARAMS/ ONLINE, MAXINT, RMAXLG, JUNK(4)
COMMON /PROBLM/ NN, NA, NP, NOIS, NCOM, FROM, TO, ABAR, LOWB, UPB, FLOW
COMMON LABEL, EPS, JREC, LABLIS, INDEX, INDTO, NEXL
*****

SET UP INDICES, AND CHECK INITIAL CIRCULATION
( FLOW TO EACH NODE SHOULD = FLOW FROM IT)

DO 1 J=1, NN
LABEL(J)=0
INDTO(J)=0
INDEX(J)=0
1 CONTINUE
L=0
DO 2 I=1, NA
J=TO(I)
LABEL(J)=LABEL(J)+FLOW(I)
NEXL(I)=INDTO(J)
INDTO(J)=I
J=FROM(I)
LABEL(J)=LABEL(J)-FLOW(I)
IF(J.EQ.L) GO TO 2
L=J

```



```

      IF(INDEX(J).NE.0) GO TO 83
      INDEX(J)=I
2     CONTINUE
      DO 3 J=1,NN
      IF(LABEL(J).NE.0) GO TO 91
      IF(INDEX(J).EQ.0) GO TO 82
3     CONTINUE
C
      DO 100 I=1,NA
      S=FROM(I)
      T=TO(I)
C     TEST WHICH STATE LINK I IS IN
101  IF(ABAR(I)) 12,11,10
10   TEMP=FLOW(I)-LOWB(I)
      IF(TEMP) 20,100,30
11   TEMP=FLOW(I)-UPB(I)
      IF(TEMP.GT.0) GO TO 31
      IF(FLOW(I).LT.LOWB(I)) GO TO 20
      GO TO 100
12   TEMP=FLOW(I)-UPB(I)
      IF(TEMP) 20,100,30
C
C     *****
C     *
C     * LABELLING PROCESS *
C     *
C     *****
C
C     CASE BETA-2
31   TEMP=FLOW(I)-LOWB(I)
C     CASES ALPHA-2,GAMMA-2
30   DO 13 J=1,NN
      LABEL(J)=0
13   CONTINUE
      PIN=1
      LABEL(S)=-T
      TARGET=T
      EPS(S)=TEMP
      JREC(S)=I
      X=S
      GO TO 22
C
C     CASES ALPHA-1,BETA-1,GAMMA-1
20   DO 14 J=1,NN
      LABEL(J)=0
14   CONTINUE
      PIN=1
      LABEL(T)=S
      TARGET=S
      EPS(T)=-TEMP
      JREC(T)=I
      X=T
      GO TO 22
C
C     PICK UP NEXT LABELLED NODE X (NON-B.T. IF ALL DONE)
21   PIN=PIN-1
      IF(PIN.EQ.0) GO TO 40
      X=LABELIS(PIN)
C
C     LABEL ALONG FORWARD ARCS
22   L=INDEX(X)
      DO 23 J=L,NA
      IF(FROM(J).NE.X) GO TO 26
      TEMP=TO(J)
      IF(LABEL(TEMP).NE.0) GO TO 23
      IF(ABAR(J).LE.0) GO TO 24
      TEMP=LOWB(J)-FLOW(J)
      IF(TEMP.LE.0) GO TO 23
      GO TO 25
24   TEMP=UPB(J)-FLOW(J)
      IF(TEMP.LE.0) GO TO 23

```

```

25 Y=TO(J)
   LABEL(Y)=X
   JREC(Y)=J
   EPS(Y)=MIN(EPS(X),TEMP)
   LABLIS(PIN) =Y
   PIN=PIN+1
   IF(Y.EQ.TARGET) GO TO S0
23 CONTINUE
C
C LABEL ALONG BACKWARD ARCS
26 J=INOT(X)
   GO TO 70
29 J=NEXL(J)
70 IF(J.EQ.0) GO TO 21
   Y=FROM(J)
   IF(LABEL(Y).NE.0) GO TO 29
   IF(ABAR(J).LT.0) GO TO 27
   TEMP=FLOW(J)-LOWB(J)
   IF(TEMP.LE.0) GO TO 29
   GO TO 28
27 TEMP=FLOW(J)-UPB(J)
   IF(TEMP.LE.0) GO TO 29
28 LABEL(Y)=-X
   JREC(Y)=J
   EPS(Y)=MIN(EPS(X),TEMP)
   LABLIS(PIN) =Y
   PIN=PIN+1
   IF(Y.EQ.TARGET) GO TO S0
   GO TO 29
C
C *****
C * NON-BREAKTHROUGH *
C *****
C
40 DELTA=MAXINT
C
C FIND CHANGE IN NODE NUMBERS
DO 41 J=1,NA
  X=FROM(J)
  Y=TO(J)
  IF(LABEL(X).EQ.0) GO TO 42
  IF(LABEL(Y).NE.0) GO TO 41
  IF(ABAR(J).LE.0) GO TO 41
  IF(FLOW(J).GT.UPB(J)) GO TO 41
C   SET A1
  IF(DELTA.GT.ABAR(J)) DELTA=ABAR(J)
  GO TO 41
C
42 IF(LABEL(Y).EQ.0) GO TO 41
   IF(ABAR(J).GE.0) GO TO 41
   IF(FLOW(J).LT.LOWB(J)) GO TO 41
C   SET A2
  IF(DELTA.GT.-ABAR(J)) DELTA=-ABAR(J)
41 CONTINUE
C EXIT IF NON-FEASIBLE, I.E. A1 AND A2 BOTH EMPTY
  IF(DELTA.EQ.MAXINT) GO TO 90
C
C CHANGE NODE NUMBERS
DO 45 J=1,NA
  X=FROM(J)
  Y=TO(J)
  IF(LABEL(X).NE.0) GO TO 44
  IF(LABEL(Y).NE.0) ABAR(J)=ABAR(J)+DELTA
  GO TO 45
44 IF(LABEL(Y).EQ.0) ABAR(J)=ABAR(J)-DELTA
45 CONTINUE
   GO TO 101
C
C *****

```

```

C      *           *
C      * BREAKTHROUGH *
C      *           *
C      *~~~~~*
C
50 EP=EPS(Y)
52 X=LABEL(Y)
   J=JREC(Y)
   IF(X.LT.0) GO TO S1
C
C      FLOW CHANGE - FORWARD ARC
   FLOW(J)=FLOW(J)+EP
   Y=X
   IF(X.NE.TARGET) GO TO S2
   GO TO 101
C
C      FLOW CHANGE - BACKWARD ARC
1  X=-X
   FLOW(J)=FLOW(J)-EP
   Y=X
   IF(X.NE.TARGET) GO TO S2
   GO TO 101
C
100 CONTINUE
C      ALL DONE
   IFEAS=0
99 RETURN
C
C      ERROR RETURNS
90 IFEAS=1
C      NON-FEASIBLE RETURN
   GO TO 99
91 IFEAS=-1
C      INITIAL CIRCULATION INVALID
   GO TO 99
92 IFEAS=-2
C      LINKS MISSING
   GO TO 99
93 IFEAS=-3
C      LINKS OUT OF ORDER
   GO TO 99
   END

```

```

SUBROUTINE UNFEAS(IFEAS)
C
C   DIAGNOSE LOCATION WHERE NON-FEASIBILITY WAS DETECTED BY KILTER
C
REAL NAME(8,150),LENP(9),CNAME(18,60),DNAME(7,50),COTAB(150)
LOGICAL ONLINE
INTEGER IDIS(150),PER(300),POINT(300),LOWB(2000),UPB(2000),
  ABAR(2000),FLOW(2000),FROM(2000),TO(2000),COST(2000),SETUB(2000),
  SETLB(2000)
COMMON /FILE/ CNAME,NAME,DNAME,COTAB,NPERS,LENP,IDIS,PER,POINT,
1 COST,SETUB,SETLB
COMMON /PROBLM/ NN,NA,NP,NOIS,NCOM,FROM,TO,ABAR,LOWB,UPB,FLOW
COMMON /PARAMS/ ONLINE,MAXINT,RMAXLG,IOUCOM,IOUDAT,IOULOG,IOUNET
C
WRITE(IOULOG,13)
13 FORMAT(///62H THE FLOW SYSTEM DOES NOT MEET THE REQUIREMENTS SPECI
  FIED /62H WHICH WERE FOUND TO BE IMPOSSIBLE TO SATISFY WHILE PROCE
  SSSING )
C
C   IDENTIFY TYPE OF ARC INVOLVED
C
I=FROM(IFEAS)
J=TO(IFEAS)
I=POINT(I)
J=POINT(J)
IF(I.EQ.0) GO TO 14
IF(J.EQ.0) GO TO 15
IF(IDIS(I).EQ.0.AND.IDIS(J).EQ.0) GO TO 17
IF(IDIS(I).EQ.-2) GO TO 30
C
C   ACTUAL ROUTE
C
WRITE(IOULOG,26) PER(I),(NAME(L,I),L=1,8),(NAME(L,J),L=1,8)
26 FORMAT(20H THE ROUTE IN PERIOD ,I4/6H FROM ,8A4,4H TO ,8A4)
GO TO 18
C
C   COLLECTION CENTROID
C
14 WRITE(IOULOG,20) PER(J),(NAME(L,J),L=1,8)
20 FORMAT(23H THE ARISINGS IN PERIOD ,I4,4H AT ,8A4)
GO TO 18
C
15 IF(IDIS(I).EQ.-2) GO TO 16
C
C   INCINERATOR OR LANDFILL PERIOD ARC
C
30 WRITE(IOULOG,21) PER(I),(NAME(L,I),L=1,8)
21 FORMAT(20H THE INPUT IN PERIOD ,I4,4H TO ,8A4)
GO TO 18
C
C   LANDFILL SITE TOTAL ARC
C
16 WRITE(IOULOG,22) (NAME(L,I),L=1,8)
22 FORMAT(14H THE INPUT TO ,8A4)
GO TO 18
C
C   TRANSFER STATION
C
17 WRITE(IOULOG,23) PER(I),(NAME(L,I),L=1,8)
23 FORMAT(25H THE THROUGHPUT IN PERIOD ,I4,4H OF ,8A4)
C
18 RETURN
END

```

```

SUBROUTINE OUTPUT(NETOUT)
C
C IF NETOUT IS .TRUE., OUTPUT COMPLETE FLOW NETWORK TO IOUNET
C ELSE OUTPUT COSTS ONLY TO IOULOG
C
REAL NAME(8,150),DNAME(7,50),CNAME(18,60),LENP(9),CSUM(9,S1),
1 COLSUM(9),COLSM2(9),COTAB(150)
INTEGER IOIS(150),PER(300),POINT(300),COST(2000),LOWB(2000),
1 UPB(2000),FROM(2000),TO(2000),FLOW(2000),ABAR(2000),SETUB(2000)
2 ,SETLB(2000)
LOGICAL NETOUT,ONLINE,MKD(150),MKD1
COMMON /PARAMS/ ONLINE,MAXINT,RMAXLG,IOUCOM,IOUDAT,IOULOG,IOUNET
COMMON /PROBLM/ NN,NA,NP,NOIS,NCOM,FROM,TO,ABAR,LOWB,UPB,FLOW
COMMON /FILE/ CNAME,NAME,DNAME,COTAB,NPERS,LENP,IOIS,
1 PER,POINT,COST,SETUB,SETLB
COMMON CSUM,COLSUM,COLSM2,MKD
C
C CSUM(J,I) - TOTAL COST TO DISTRICT I IN PERIOD J
C TOTALLED IN FLOATING-POINT TO AVOID POSSIBLE OVERFLOWS
C COUNTY IS TREATED AS DISTRICT S1
C
DO 1 I=1,9
DO 1 J=1,S1
CSUM(I,J)=0.0
1 CONTINUE
IF(.NOT.NETOUT) GO TO 3
IOU=IOUNET
C
WRITE(IOUNET,2)
2 FORMAT(37H1***** OPTIMISED REFUSE FLOWS ***** //)
C
IF(NCOM.GT.0) WRITE(IOUNET,12) ((CNAME(I,J), I=1,18),J=1,NCOM)
12 FORMAT(1X,18A4)
GO TO 4
C
C IDENTIFY CURRENT EXCLUSIONS
C
3 IOU=IOULOG
4 MKD1=.FALSE.
DO 10 I=1,NP
MKD(I)=.FALSE.
10 CONTINUE
DO 14 I=1,NA
IF(SETUB(I).EQ.UPB(I)) GO TO 14
IF(UPB(I).NE.0) GO TO 9001
J=FROM(I)
J=POINT(J)
MKD(J)=.TRUE.
MKD1=.TRUE.
14 CONTINUE
C
C IF THERE ARE EXCLUSIONS, LIST THEM
C IF(.NOT.MKD1) GO TO 41
WRITE(IOU,17)
17 FORMAT(//22H EXCLUDED FACILITIES - //)
DO 15 I=1,NP
IF(MKD(I)) WRITE(IOU,16) (NAME(J,I),J=1,8)
16 FORMAT(1X,8A4)
15 CONTINUE
C
41 WRITE(IOU,11) NPERS,(LENP(I),I=1,NPERS)
11 FORMAT(//13,20H PERIODS, LENGTHS IN YEARS - /9FS.1)
C
C LASTI=0
C LOOK AT EACH ARC, OUTPUT AND RECORD COST AS APPROPRIATE
DO 40 IA=1,NA
IFR=FROM(IA)
I=POINT(IFR)
C
C ARISINGS -
IF(I.EQ.0) GO TO 40

```

```

IT=TO<IA>
J=POINT<IT>
K=PER<IFR>
IF=FLOW<IA>
ID=IDIS<I>
C LANDFILL SITE, INCINERATOR -
  IF<J.EQ.0> IF<ID+1> 91,30,9001
  IF<ID.EQ.-2> GO TO 30
C TRANSFER STATION -
  IF<ID.EQ.0.AND.IDIS<J>.EQ.0> GO TO 30
C
C ACTUAL ROUTE
  IF<MKD<I>> GO TO 40
  IF<I.EQ.LASTI> GO TO 43
  LASTI=I
  IF<NETOUT> WRITE<IOUNET,42> <NAME<L,I>,L=1,8>
42 FORMAT(///25H DISPOSAL OF REFUSE FROM ,8A4/7H PERIOD,10X,
1 11HDESTINATION,11X,22HANNUAL FLOW TOTAL FLOW /)
43 IF<IF.EQ.0> GO TO 40
  IFAN=INT<FLOAT<IF>/LENP<K>+0.5>
  IF<NETOUT> WRITE<IOUNET,49> K,<NAME<L,J>,L=1,8>,IFAN,IF
49 FORMAT<IS,2X,8A4,I8,2H00,I9,2H00>
  IF<ID.EQ.0> ID=S1
  CSUM<K, ID>=CSUM<K, ID>+FLOAT<COST<IA>>*FLOAT<IF>
  GO TO 40
C
C TRANSFER STN. OR INCINERATOR, OR LANDFILL PERIOD ARC
C
C 30 IF<MKD<I>.OR.IF.EQ.0> GO TO 40
  IF<I.EQ.LASTI> GO TO 31
  LASTI=I
  IF<NETOUT> WRITE<IOUNET,32> <NAME<L,I>,L=1,8>
32 FORMAT(///15H THROUGHPUT OF ,8A4/30H PERIOD ANNUAL FLOW TOTAL FLOW
1 /)
31 IFAN=INT<FLOAT<IF>/LENP<K>+0.5>
  IF<NETOUT> WRITE<IOUNET,33> K,IFAN,IF
33 FORMAT<IS,I11,2H00,I10,2H00>
  CSUM<K,61>=CSUM<K,61>+FLOAT<COST<IA>>*FLOAT<IF>
  GO TO 40
C
C LANDFILL SITE TOTAL ARC
C
C 91 IF<.NOT.NETOUT.OR.MKD<I>> GO TO 40
  LASTI=I
  IF<IF.EQ.0> GO TO 93
  IFS=UPB<IA>-IF
  WRITE<IOUNET,92> IF,IFS
92 FORMAT</11H TOTAL USED,9X,I8,2H00/16H SPACE REMAINING,I12,2H00>
  GO TO 40
93 WRITE<IOUNET,94> <NAME<L,I>,L=1,8>,UPB<IA>
94 FORMAT(///15H UNUSED SITE - ,8A4/16H SPACE REMAINING,I12,2H00)
40 CONTINUE
C
C PRINT THE COSTS
  IF<.NOT.NETOUT> GO TO 80
  WRITE<IOU,60>
60 FORMAT<1H1,61X,16HSUMMARY OF COSTS //55X,11HTOTAL COSTS //>
  WRITE<IOU,61> <I,I=1,NPERS>
61 FORMAT<8H PERIOD,17X,9I10>
  WRITE<IOU,76>
76 FORMAT<>
C
C DO 67 I=1,NDIS
  WRITE<IOU,63> <DNAME<J,I>,J=1,7>,<CSUM<J,I>,J=1,NPERS>
63 FORMAT<1X,7A4,9F10.0>
67 CONTINUE
C
C DO 64 J=1,NPERS
  COLSUM<J>=0.0
  DO 62 I=1,NDIS
    COLSUM<J>=COLSUM<J>+CSUM<J,I>

```

```

62 CONTINUE
   COLSM2(J)=COLSUM(J)+CSUM(J,S1)
64 CONTINUE
C
   WRITE(IOU,65) (COLSUM(J),J=1,NPERS)
65 FORMAT(/16H DISTRICT TOTALS ,13X,9F10.0)
   WRITE(IOU,66) (CSUM(J,S1),J=1,NPERS)
66 FORMAT(/7H COUNTY ,22X,9F10.0)
   WRITE(IOU,68) (COLSM2(J),J=1,NPERS)
68 FORMAT(/15H OVERALL TOTALS ,14X,9F10.0)
C
   WRITE(IOU,69)
69 FORMAT(/29X,11HALL PERIODS /)
C
80 GSUM=0.0
   DO 70 I=1,NOIS
     SUM=0.0
     DO 71 J=1,NPERS
       SUM=SUM+CSUM(J,I)
71 CONTINUE
     IF(NETOUT) WRITE(IOU,63) (DNAME(J,I),J=1,7),SUM
     GSUM=GSUM+SUM
70 CONTINUE
C
   IF(NETOUT) WRITE(IOU,65) GSUM
   SUM=0.0
   DO 72 J=1,NPERS
     SUM=SUM+CSUM(J,S1)
72 CONTINUE
   IF(NETOUT) WRITE(IOU,66) SUM
   GSUM=GSUM+SUM
   IF(NETOUT) GO TO 81
   WRITE(IOU,82) GSUM
82 FORMAT(/14H TOTAL COST - ,F12.0)
   GO TO 83
81 WRITE(IOU,73) GSUM
73 FORMAT(/12H GRAND TOTAL ,15X,F12.0//55X,12HANNUAL COSTS //)
   WRITE(IOU,61) (I,I=1,NPERS)
   WRITE(IOU,76)
C
C   REDUCE COSTS TO AN ANNUAL BASIS
83 DO 75 J=1,NPERS
   COLSUM(J)=0.0
   DO 74 I=1,NOIS
     CSUM(J,I)=CSUM(J,I)/LENP(J)
     COLSUM(J)=COLSUM(J)+CSUM(J,I)
74 CONTINUE
     CSUM(J,S1)=CSUM(J,S1)/LENP(J)
     COLSM2(J)=COLSUM(J)+CSUM(J,S1)
75 CONTINUE
C
   IF(NETOUT) GO TO 84
   WRITE(IOU,85) (J,COLSM2(J),J=1,NPERS)
85 FORMAT(/13H ANNUAL COSTS //15H PERIOD COST /9(I4,F14.0//)
   GO TO 100
C
C   PRINT AS FOR TOTAL COSTS
84 DO 77 I=1,NOIS
   WRITE(IOU,63) (DNAME(J,I),J=1,7),(CSUM(J,I),J=1,NPERS)
77 CONTINUE
   WRITE(IOU,65) (COLSUM(J),J=1,NPERS)
   WRITE(IOU,66) (CSUM(J,S1),J=1,NPERS)
   WRITE(IOU,68) (COLSM2(J),J=1,NPERS)
100 RETURN
C
9001 WRITE(IOULOG,9101)
9101 FORMAT(22H SYSTEM ERROR - OUTPUT )
STOP 7701
END

```

LISTING OF THE DATA USED FOR THE TRANSHIPMENT PROGRAM

1. DISTRICT OF COLUMBIA
2. ALABAMA
3. ALASKA
4. ARIZONA
5. ARKANSAS
6. CALIFORNIA
7. COLORADO
8. CONNECTICUT
9. DELAWARE
10. FLORIDA
11. GEORGIA
12. HAWAII
13. ILLINOIS
14. INDIANA
15. IOWA
16. KANSAS
17. KENTUCKY
18. LOUISIANA
19. MAINE
20. MARYLAND
21. MASSACHUSETTS
22. MICHIGAN
23. MINNESOTA
24. MISSISSIPPI
25. MISSOURI
26. MONTANA
27. NEBRASKA
28. NEVADA
29. NEW HAMPSHIRE
30. NEW JERSEY
31. NEW MEXICO
32. NEW YORK
33. NORTH CAROLINA
34. NORTH DAKOTA
35. OHIO
36. OKLAHOMA
37. OREGON
38. PENNSYLVANIA
39. RHODE ISLAND
40. SOUTH CAROLINA
41. SOUTH DAKOTA
42. TENNESSEE
43. TEXAS
44. UTAH
45. VERMONT
46. VIRGINIA
47. WASHINGTON
48. WEST VIRGINIA
49. WISCONSIN
50. WYOMING

S 7 0.0 0.06964 0.01203 0.0 0.0 0.0
 0.33 1.0 1.0 1.0 1.0
 ANNUAL AVERAGES DATA
 TYSELEY NEW WORKS OPENS AT BEGINNING OF 1978
 COSTS IN POUNDS; QUANTITIES IN TONNES
 2.5 CU.METRES PER TONNE ASSUMED IN LANDFILL
 *COL
 CCOV COVENTRY DISTRICT
 2 935
 CSON SOLIHULL N. DISTRICT
 5 198
 CSDE SOLIHULL S.E. DISTRICT
 5 32
 CSDW SOLIHULL S.W. DISTRICT
 5 430
 CLIF LIFFORD DISTRICT
 1 552
 CTYS TYSELEY DISTRICT
 1 371
 CCBS CASTLE BROMWICH S. DISTRICT
 1 497
 CCBN CASTLE BROMWICH N. DISTRICT
 1 45
 CSNW SANDWELL N.W. DISTRICT
 4 133
 CSSW SANDWELL S.W. DISTRICT
 4 158
 CSSE SANDWELL S.E. DISTRICT
 4 62
 CSNE SANDWELL N.E. DISTRICT
 4 265
 CRPK ROTTON PARK DISTRICT
 1 293
 CMON MONTAGUE ST. DISTRICT
 1 461
 CPER PERRY BARR DISTRICT
 1 487
 CWOL WOLVERHAMPTON DISTRICT
 7 713
 CWNE WALSALL N.E. DISTRICT
 6 28
 CWSE WALSALL S.E. DISTRICT
 6 56
 CWW WALSALL W. DISTRICT
 6 473
 CSUT SUTTON COLDFIELD DISTRICT
 1 217
 CDN DUDLEY N. DISTRICT
 3 460
 CDSE DUDLEY S.E. DISTRICT
 3 120
 CDSW DUDLEY S.W. DISTRICT
 3 143
 *TRA
 XRPK ROTTON PARK ST. WORKS
 0 50048.05
 XSOL SOLIHULL WORKS
 0 50048.05
 XW/S WALSALL/SANDWELL WORKS
 0 50048.05
 XBEN BENTLEY LANE TRANSFER STATION
 0 120022.S1 3
 XBAR BARNFIELD RD. TRANSFER STATION
 0 120022.S1 1 1
 *INC
 IPER PERRY BARR WORKS
 803 803
 ICBR CASTLE BROMWICH WORKS
 548 548 0
 ILIF LIFFORD WORKS
 497 497 0

IMON MONTAGUE ST. WORKS
 240 240 0 1 2
 ITYO OLD TYSELEY WORKS
 357 357 0 1 2
 ISUT SUTTON COLDFIELD WORKS
 192 192
 ICO2 COVENTRY WORKS (2 STREAM)
 1400 2016
 IDUD DUOLEY WORKS
 697 697
 IWOL WOLVERHAMPTON WORKS
 748 748
 IIMI I.M.I. PLANT (BASIC LOAD)
 150 150
 IMIX I.M.I. PLANT (ADDITIONAL LOAD)
 225 225
 ITYN NEW TYSELEY WORKS
 1143 1143 3
 ICO3 COVENTRY WORKS (3RD STREAM)
 600 600
 IPAK PACKINGTON LANDFILL SITE
 0 500

*TIP

TBEL BENTLEY LANE SITE
 348
 TPOK POUK HILL SITE
 920 2 2
 TTIV TIVIDALE SITE
 3944 2
 TMUK MUCKLOW HILL SITE
 36
 TLEY THE LEYS SITE
 66
 THAY HAY LANE SITE
 487 1 3
 TOAK OAK FARM SITE
 2708 2
 TFAR LONG HAUL SITE
 20000 2
 TBAL BLUE ROCK/ALLSOP'S SITE
 7380 1
 TBOD BOOTH'S LANE SITE
 600
 TBIR BIRCH COPPICE SITE
 1540

*ROU

XRPK	IMON	31.5	ITYO	57.8					
	ITYN	57.8	IIPER	38.6	ICBR	75.2	ILIF	53.7	
	TBOD	45.6	TBAL	44.4	TBIR	93.0			
	THAY	88.8	TMUK	43.4	TPOK	73.6	TBEL	78.8	
	ICO2	134.7	ICO3	134.7	IIMI	38.6			
	IMIX	38.6	ISUT	78.8	TFAR	183.0	TTIV	54.7	
	TOAK	112.5							
XSOL	ICO3	80.0	ICO2	80.0	TFAR	112.4	ICBR	71.0	ISUT
	IPAK	49.6	ITYO	39.0					
	ITYN	39.0							
XW/S	ICO3	114.8	ICO2	114.8	IIPER	38.0	IWOL	36.0	IDUD
	TBAL	54.4	TBOD	40.0	TBIR	63.4			
	TBEL	22.2	ITYO	63.4					
	ITYN	63.4	ICBR	57.6	ISUT	57.6			
	ILIF	91.2	TMUK	54.0	TFAR	136.4	IIMI	30.0	
	IMIX	30.0	TTIV	40.8	TOAK	70.4			
XBEN	IWOL	40.8	IDUD	84.6	ISUT	69.2	IIPER	47.0	ICO2
	ITYO	95.4							
	ITYN	95.4	ICBR	70.0	TMUK	63.4			
	TFAR	150.8	IIMI	47.0					
	IMIX	47.0							
	TOAK	81.6	TTIV	58.4					
XBAR	IIPER	58.8	IIMI	58.8					
	IMIX	58.8	TPOK	39.0	IDUD	24.8	IWOL	36.6	TMUK
	ISUT	77.8	ICO2	106.8	ICO3	106.8	ITYO	85.2	

	ITYN	86.2	ICBR	86.2					
	TFAR	157.0	TOAK	52.2	TTIU	24.0			
CCDU	IC03	35.2	IC02	35.2	TFAR	63.6	IPAK	55.2	
CSON	IPAK	39.4	ICBR	26.0	ISUT	34.6	ITYO	43.0	
	ITYN	43.0	TFAR	68.8					
	XSOL	59.0	IC02	72.0	IC03	72.0			
CDOE	IPAK	39.6	THAY	45.0	IC02	62.4	IC03	62.4	XSOL
COW	THAY	22.6	ITYO	37.4				45.0	TFAR
	ITYN	37.4	ILIF	55.0	IC02	80.0	IC03	80.0	
	XSOL	22.6	IPAK	42.0					
CLIF	IMON	53.6	ILIF	23.2	XRPK	47.2	ITYO	52.0	
	ITYN	52.0							
	THAY	63.6							
	XSOL	63.6	TMUK	52.0	IC02	138.0	IC03	138.0	
CTYS	IC02	96.6	IC03	96.6	XRPK	40.8	ITYO	23.0	
	ITYN	23.0							
	THAY	43.0							
	IMON	32.0	ICBR	50.0	ILIF	44.0	XSOL	43.0	
	IPAK	54.6	TMUK	63.2	TB00	66.0			
CCBS	IPER	41.6	IMON	38.4	ISUT	28.2	IPAK	42.6	THAY
	ITYO	31.0						65.0	ICBR
	ITYN	31.0							21.2
	XSOL	65.0							
CCBN	IPER	23.2	ICBR	31.0	ISUT	26.8	IMON	44.0	XRPK
	TMUK	76.8	IPAK	68.8	XBEN	63.8		46.6	TBEL
CSNW	IPER	48.6	TPOK	31.8	IDUD	32.8	XW/S	22.6	XRPK
	TB00	37.8	TBAL	34.4				45.6	TTIU
	TOAK	64.2	IWOL	40.4	TMUK	36.0	XBAR	18.4	
	TBEL	39.0	XBEN	39.0					
CSSW	TMUK	24.0	XRPK	51.6	XW/S	49.6	TTIU	37.6	TOAK
	XBAR	33.6						79.2	IDUD
	TBAL	18.7							24.0
CSSE	XBAR	35.2							
	XRPK	28.8	TMUK	32.0	IPER	41.0	TTIU	31.2	
	TBAL	26.8							
CSNE	TBEL	39.0	XBEN	39.0	IPER	33.0	TPOK	30.6	IDUD
	TBAL	36.7	TB00	23.4				49.6	XRPK
	TMUK	43.2	XBAR	36.8					35.4
	XW/S	22.2	TTIU	28.6	TOAK	75.0			
CRPK	XRPK	19.6	TMUK	37.4	IPER	44.4	IMON	35.2	ITYO
	ITYN	48.8						40.8	
	TBAL	44.4							
	ILIF	34.6							
CMON	TMUK	67.8	IMON	16.0	XRPK	34.0	ITYO	29.0	
	ITYN	29.0							
	IPER	33.6							
	ICBR	46.4	ILIF	50.4	THAY	78.4	XSOL	78.4	TBEL
COPER	IPER	15.8	TBEL	51.8	TMUK	57.6	XBEN	51.8	XRPK
	TB00	21.0	TBAL	54.6				31.8	IMON
	ITYO	53.6							35.2
	ITYN	53.6							
	ICBR	44.4	ISUT	45.8					
CWOL	IWOL	20.8	TBEL	41.6	TPOK	46.0	XW/S	52.0	TLEY
	TTIU	56.4	TOAK	51.0	XBAR	43.0			54.6
	XBEN	41.6							
CWNE	XBEN	41.0	XW/S	52.0	TPOK	38.2	TBEL	41.0	
	TB00	42.6	TBIR	17.6					
CWSE	IPER	38.8	XW/S	40.2	TPOK	40.8	TBEL	41.4	XBEN
	TB00	21.0	TBIR	44.0					41.4
CWH	XBEN	27.2	XW/S	24.0	IPER	41.8	XRPK	59.4	TFAR
	TB00	34.0	TBAL	58.4	TBIR	42.0		145.4	TPOK
	TBEL	27.2	IWOL	48.8					20.8
CSUT	ISUT	32.4	ICBR	41.6	IPER	44.4	TFAR	97.6	TBEL
	IPAK	61.4	XBEN	76.4	TB00	33.0	TBIR	60.6	
CDN	XBAR	36.0							
	TTIU	39.2	TOAK	24.0	XRPK	76.8	ILIF	92.4	IPER
	IDUD	22.6	TLEY	28.2	TBAL	34.4			83.2
CDSE	TMUK	23.0	IDUD	30.4	XRPK	56.8	ILIF	76.0	IPER
	TBAL	30.5						75.6	TOAK
CDSW	TOAK	48.0	TMUK	41.6	TLEY	29.6	IDUD	41.6	TBAL
*DIS								49.6	

- 1 BIRMINGHAM
- 2 COVENTRY
- 3 DUDLEY
- 4 SANDWELL
- 5 SOLIHULL
- 6 WALSALL
- 7 WOLVERHAMPTON

APPENDIX ESAMPLE OUTPUT FROM THE TRANSHIPMENT PROGRAM

The following pages show sample pages from the output produced by the program in Appendix C, using the data in Appendix D. The first page shows the beginning of the output, with comments and a list of excluded facilities; the second, from the middle of the output, shows the form of the flow network results; the third is the summary of costs given at the end of the output. The complete output from this run was more than 20 pages long.

ANNUAL AVERAGES DATA
 COSTS IN POUNDS, QUANTITIES IN TONNES
 2.5 CU.METRES PER TONNE ASSUMED IN LANDFILL

EXCLUDED FACILITIES -

BENTLEY LANE TRANSFER STATION
 BARNFIELD RD. TRANSFER STATION
 COVENTRY WORKS (3RD STREAM)
 OAK FARM SITE

3 PERIODS, LENGTHS IN YEARS -
 2.8 4.0 4.0

THROUGHPUT OF ROTTON PARK ST. WORKS
 PERIOD ANNUAL FLOW TOTAL FLOW

1	29500	59000
2	28600	114500
3	27200	108900

THROUGHPUT OF SOLIHULL WORKS
 PERIOD ANNUAL FLOW TOTAL FLOW

1	13000	25900
2	9000	36100
3	12600	50400

THROUGHPUT OF WALSALL/SANDWELL WORKS
 PERIOD ANNUAL FLOW TOTAL FLOW

2	48200	192600
3	50000	200000

THROUGHPUT OF PERRY BARR WORKS
 PERIOD ANNUAL FLOW TOTAL FLOW

1	85000	170000
2	77500	310000
3	77500	310000

THROUGHPUT OF CASTLE BROMWICH WORKS
 PERIOD ANNUAL FLOW TOTAL FLOW

1	53000	106000
2	53000	212000
3	53000	212000

DISPOSAL OF REFUSE FROM ROTTON PARK ST. WORKS

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
1	NEW TYSELEY WORKS		
1	I.M.I. PLANT (BASIC LOAD)	14500	29000
2	I.M.I. PLANT (BASIC LOAD)	15000	30000
2	I.M.I. PLANT (ADDITIONAL LOAD)	6100	24500
3	I.M.I. PLANT (BASIC LOAD)	22500	90000
3	I.M.I. PLANT (ADDITIONAL LOAD)	5000	20000
		22200	88000

DISPOSAL OF REFUSE FROM SOLIHULL WORKS

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
1	COVENTRY WORKS (2 STREAM)	13000	26000
2	COVENTRY WORKS (2 STREAM)	8000	36100
3	COVENTRY WORKS (2 STREAM)	12600	50400

DISPOSAL OF REFUSE FROM WALSHALL/SANDWELL WORKS

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
2	PERRY BARR WORKS	27100	100300
2	WOLVERHAMPTON WORKS	12200	40000
2	I.M.I. PLANT (BASIC LOAD)	8000	35500
3	PERRY BARR WORKS	25200	100600
3	WOLVERHAMPTON WORKS	14600	50300
3	I.M.I. PLANT (BASIC LOAD)	10000	40000
3	I.M.I. PLANT (ADDITIONAL LOAD)	300	1100

DISPOSAL OF REFUSE FROM COVENTRY DISTRICT

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
1	COVENTRY WORKS (2 STREAM)	80500	101000
2	COVENTRY WORKS (2 STREAM)	87000	351200
3	COVENTRY WORKS (2 STREAM)	84400	337400

DISPOSAL OF REFUSE FROM SOLIHULL N. DISTRICT

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
1	CASTLE BROMWICH WORKS	20500	41000
2	CASTLE BROMWICH WORKS	19000	79500
3	CASTLE BROMWICH WORKS	19100	76400

DISPOSAL OF REFUSE FROM SOLIHULL S.E. DISTRICT

PERIOD	DESTINATION	ANNUAL FLOW	TOTAL FLOW
1	PACKINGTON LANDFILL SITE	3300	6500
2	COVENTRY WORKS (2 STREAM)	3200	12700
3	COVENTRY WORKS (2 STREAM)	3100	12200

SUMMARY OF COSTS

TOTAL COSTS

PERIOD	1	2	3
BIRMINGHAM	497247.	706833.	461995.
COVENTRY	244350.	358224.	232806.
DUDLEY	116186.	177543.	117118.
SANDWELL	126340.	162668.	108740.
SOLIHULL	138889.	253694.	162268.
WALSALL	202561.	182544.	116406.
WOLVERHAMPTON	100240.	145820.	95817.
DISTRICT TOTALS	1425013.	1987426.	1295150.
COUNTY	1436376.	2086764.	1388449.
OVERALL TOTALS	2861389.	4074190.	2683599.

ALL PERIODS

BIRMINGHAM	1666075.
COVENTRY	835380.
DUDLEY	410847.
SANDWELL	387748.
SOLIHULL	554051.
WALSALL	801511.
WOLVERHAMPTON	341977.
DISTRICT TOTALS	4707588.
COUNTY	4811580.
GRAND TOTAL	9619178.

ANNUAL COSTS

PERIOD	1	2	3
BIRMINGHAM	248624.	176708.	115499.
COVENTRY	122175.	89556.	58201.
DUDLEY	58083.	44386.	29279.
SANDWELL	63170.	40667.	27185.
SOLIHULL	68044.	63423.	40567.
WALSALL	101281.	45636.	29101.
WOLVERHAMPTON	50120.	36480.	23954.
DISTRICT TOTALS	712507.	496857.	323788.
COUNTY	718186.	521681.	347112.
OVERALL TOTALS	1430684.	1018547.	670900.

APPENDIX FTHE MATRIX GENERATOR PROGRAM FOR THE TRANSHIPMENT
WITH GAINS MODEL

The following pages give a listing of the program used to run the transshipment with gains model described in section 6.2. This program accepts input in a form very similar to that required for the pure transshipment model (described in Appendix B), and produces output suitable for input to a linear programming package. The output format is essentially that of the SHARE system, widely adopted for other packages, and usable with the ICL LP mk. 3 package (which was the one actually used in this work).

The program is based on the earlier one, and many of the comments on that, to be found in Appendix B, are also relevant to this later system. The main routine of this program is basically the same as subroutine NEWDAT of the earlier one, the major differences being;

- (1) all data is read into arrays (notation is basically that of section 6.2) and passed to subroutine WRIMTX for output;
- (2) an additional input channel (channel 3) is used to read in a list of facilities to be excluded from the problem formulation - this is needed because the interactive facilities of the original program do not exist here;
- (3) quantities are handled as annual tonnages, rather than total tonnages for a period, for convenience in reading

the output of the LP package.

The comments given are mostly those applicable to the earlier system, and are incomplete in many cases in the new version.

The subroutine WRIMTX controls not only the format of the output, but the model used for transport costs in disposal strategies involving incineration (see section 6.2). As shown here, the model is the mixed one used for the results shown in section 6.3, so transport from transfer stations to incinerators or emergency landfill (DO loop 10) is assessed by the weighted average of the two individual costs, whereas that from collection rounds (DO loop 11) is based on the larger of the two costs. This illustrates both the methods needed. Note that all costs are scaled down by a factor of 100 before output - this is for convenience and efficiency in the LP package. All costs are initialised (in the main routine) to large values, and any activities with large costs are omitted when writing the output matrix. This is necessary to avoid producing an excessively large matrix for the LP package, with many activities which are never used, and thus wasting processing time and storage. The routine also records the number of rows and columns in the matrix produced, and the number of non-zero elements, and prints these at the end, together with an estimate of the storage required for the "problem file" in the ICL LP mk. 3 package. This last feature will obviously be irrelevant for other systems and could be removed without repercussions.

The routine automatically provides names for every row and column in the matrix. Single-character codes are used

to refer to each of the subscripts (collection centroids, transfer stations, incinerators, landfill sites, time periods), and the names are built up from these. The comments at the start of the routine should be read in conjunction with section 6.2 to decipher these codes. Note that the main routine also refers to the alphabetic codes (provided by the BLOCK DATA subprogram), and writes a series of comments in the matrix file giving the full name and single-character code for each point. The output from the LP package is quite hard to decipher, despite these provisions; it is easiest to concentrate on the row results, which indicate the flows through each facility, resorting to the column figures (flows between particular facilities) only when absolutely necessary.

The format of the input data for this program is very similar to that for the previous one. The differences are as follows:

Line 1 Columns 1-38. As before

Columns 39-43. Cost in pence per tonne-minute of transport of residue from incinerators.

Columns 44-48. Percentage annual growth in this cost.

Columns 49-53. Percentage annual growth in the cost of operating incinerator plants.

Columns 54-58. Percentage annual growth in the cost of operating landfill sites.

Columns 59-63. Volume required for crude refuse in landfill sites (cubic metres per tonne).

Columns 64-68. Volume required for incinerator residue in landfill sites (cubic metres per tonne).

Incinerators (figures on second line). The capacities should be maxima rather than averages. Two additional figures are required at the end of the line:

Columns 20-24. Fraction (not percentage) of the time for which the plant is unavailable and refuse must be diverted.

Columns 25-29. Fraction by weight of the input refuse which is produced as residue.

Landfill sites. Capacities must be given in cubic metres rather than tonnes.

Routes. Links from incinerator plants to landfill sites (for disposal of residue) are required, in addition to the previous types (this is needed even if the residue fraction is specified as zero, though obviously the cost is irrelevant and no use will be made of the link).

Conversion of this program to run on other computer systems may be rather more difficult than in the case of the pure transshipment model, for several reasons. One is the size of the program; though it took only about 100 seconds of milltime to compile and run (using the XFIV compiler and the data in Appendix G), it occupied 57792 words of core. Nearly all of this is occupied by arrays - in fact the three major arrays CIX, CJX and CKX occupy a total of 45900 words. A drastic reduction in core usage could therefore be obtained by restricting the dimensions of these arrays. The most useful (and least restrictive) way would be to limit the number of time periods which can be used; the program as given will work for up to 9

periods, but no more than 5 were ever used in the course of the study. Reducing the number of time periods to 5 would save 21624 words (if all relevant arrays were reduced in size), bringing the program down to about 46000 words. Reductions in the number of sources and disposal facilities which can be handled would reduce it still further, though if a wide range of options need to be studied, this might become inconvenient. (However, alternatives which are excluded using the special facility in this program do not need to be counted when deciding on the necessary size of these arrays, since they are ignored at the input stage). The error checks in the input stage, which prevent these arrays overflowing their bounds, should also be altered if the sizes of the arrays are reduced; if the number of time periods is reduced, it would be advisable to introduce a check to prevent array overflow on this dimension as well (at present, using an I1 format, overflow is inherently impossible).

Another potential problem in adapting this program is the more extensive use of non-standard facilities of the FORTRAN language, compared to the pure transshipment program.

Literal constants between primes (') appear in many FORMAT statements, and in DATA statements in subroutine WRIMTX and the BLOCK DATA subprogram. To conform to ISO standard FORTRAN, these should be replaced by H format codes, but this enhancement of the standard is widely available. So is the END = facility, to transfer control

when a READ is attempted at the end of an input file; this is used in the statement labelled 40 in the main routine, and if this facility is not available, it would be necessary to use a special code to indicate the end of input on this file, and test for the code in the program. The STOP n statement is used in several places as an error halt; it would be better to replace these with proper error messages. Two 1900 system routines are used. COPY is called several times in subroutine WRIMTX; its function is to copy characters from one place to another, and its use here is simply to avoid repeated subscripting. If the variables ALI, ALJ, ALK, ALL, ALM are replaced by ALPHA(I), ALPHA(J), etc. in the appropriate WRITE statements, these calls could be omitted; alternatively the straightforward statement ALI = ALPHA(I) (etc.) will work on most systems. RELEASE is called twice in the main routine; this simply releases the input files and is quite unnecessary (it is included in the program for historical reasons). The input channels used by the program as given are channel 1 (main input data) and channel 3 (list of facilities to be excluded, four character codes). The output channels are 2 (error messages, etc.) and 6 (output LP matrix).

```

REAL CNAME(18),EXTAB(150),COMTAB(7),LENP(9),NAME(5),
1  COTAB(150),AFAC(9),CXFAC(9),CCUFAC(9),CTUFAC(9),MIN,MAX,TOCO(6),
2  TIME(6),LTIM(50),D(20),R(35,9),V(20),Q(10,9),R(10,9),B(20,9),
3  E(20,9),CJ(10,9),CIX(35,50,9),CIFAC(9),CTFAC(9),CK(20,9),
4  CL(20,9),CJX(10,40,9),CKX(20,20,9),G(20),CRUFAC(9)
INTEGER OPEN(150),SHUT(150),IDIS(150),PTC(50)
LOGICAL FILSIT(20),LINE,OVER,LINKED(150)
INTEGER ALPHA(36),SPACE
COMMON /ALPHA/ ALPHA,SPACE
DATA COMTAB/4H*COL,4H*TRA,4H*INC,4H*TIP,4H*ROU,4H*DIS,4H
DATA IOUDAT,IOULOG/1,2/,MI,MJ,MK,ML/4*0/
DATA CIX,CJX,CKX,A,U,Q,R,B,E/23825*1.E30/
DATA D,CJ,CK,CL/470*0.0/

C
      NX=1
41  READ(3,40,END=49) EXTAB(NX)
40  FORMAT(A4)
      NX=NX+1
      GO TO 41
49  NX=NX-1
      CALL RELEASE(3)

C
      READ(IOUDAT,5) NPERS,NDIS,DRATE,GA,GCX,CCU,GCCU,CTU,GCTU,CRU,
1  GCRU,GCI,GCT,SIGC,SIGR
5  FORMAT(I1,I2,13F5.0)
      IF(NPERS.LE.0) GO TO 9001
      NPERS IS NO. OF PERIODS TO CONSIDER
      NDIS - NO. OF DISTRICTS
      DRATE - PERCENT/ANNUM DISCOUNT RATE FOR ALL COSTS
      GA - PERCENT/ANNUM GROWTH IN REFUSE ARISING
      GCX - PERCENT/ANNUM GROWTH IN COST OF TRANSFER STATION OPERATION
      CCU - COST PER MINUTE OF COLLECTION VEHICLES (PENCE)
      GCCU - PERCENT/ANNUM GROWTH IN CCU
      CTU - COST PER MINUTE OF TRANSFER VEHICLES (PENCE)
      GCTU - PERCENT/ANNUM GROWTH IN CTU

C
      READ(IOUDAT,2) (LENP(I),I=1,NPERS)
2  FORMAT(9F5.0)
      LENP(I) - LENGTH OF PERIOD I (YEARS)

C
      DO 5 I=1,NPERS
      IF(LENP(I).LE.0.0) GO TO 9001
5  CONTINUE
      IF(NDIS.LE.0.OR.NDIS.GT.50) GO TO 9002

C
      EVALUATE GROWTH FACTORS FOR ARISING,COST OF TRANSFER,
      COST OF COLLECTION VEHICLES, COST OF TRANSFER VEHICLES
      CALL GROWTH(GA,0.0,LENP,AFAC,NPERS)
      CALL GROWTH(GCX,DRATE,LENP,CXFAC,NPERS)
      CALL GROWTH(GCCU,DRATE,LENP,CCUFAC,NPERS)
      CALL GROWTH(GCTU,DRATE,LENP,CTUFAC,NPERS)
      CALL GROWTH(GCRU,DRATE,LENP,CRUFAC,NPERS)
      CALL GROWTH(GCI,DRATE,LENP,CIFAC,NPERS)
      CALL GROWTH(GCT,DRATE,LENP,CTFAC,NPERS)
      DO 1 I=1,NPERS
      AFAC(I)=AFAC(I)/LENP(I)
      CCUFAC(I)=CCUFAC(I)*CCU
      CTUFAC(I)=CTUFAC(I)*CTU
      CRUFAC(I)=CRUFAC(I)*CRU
      CXFAC(I)=CXFAC(I)
      CIFAC(I)=CIFAC(I)
      CTFAC(I)=CTFAC(I)
1  CONTINUE

C
      READ AND LOG COMMENTS
      DO 7 NCOM=1,60
      READ(IOUDAT,8) (CNAME(I),I=1,18)
8  FORMAT(18A4)
      I=LISTEL(CNAME(1),COMTAB,6)
      IF(I.NE.0) GO TO 9
      WRITE(6,100) (CNAME(I),I=1,18)

```

```

100 FORMAT(' *',18A4)
7 CONTINUE
  NCOM=61
  READ(10UDAT,8) COMAND
  I=LISTEL(COMAND,COMTAB,6)
  IF(I.EQ.0) GO TO 9004
9 IF(I.NE.1) GO TO 9005
  NCOM=NCOM-1
  LI=1
  IF(NX.NE.0) WRITE(6,45) (EXTAB(I),I=1,NX)
45 FORMAT(' *EXCLUDED -',150(' /' *',A4))
  WRITE(6,110) COMTAB(1)
C
C LOOP TO READ DATA ON EACH POINT
DO 10 NP=1,150
C
C READ CODE AND NAME, CHECK FOR COMMANDS
12 READ(10UDAT,101) COTAB(NP),NAME
101 FORMAT(A4,1X,5A8)
  I=LISTEL(COTAB(NP),EXTAB,NX)
  IF(I.NE.0) GO TO 42
  I=LISTEL(COTAB(NP),COMTAB,7)
  IF(I.EQ.0) GO TO 55
  IF(I.EQ.7) GO TO 9015
  IF(I.LT.LI.OR.I.EQ.6) GO TO 9005
  IF(I.EQ.5) GO TO 62
  LI=I
  WRITE(6,110) COTAB(NP)
110 FORMAT(' *',A4)
  GO TO 12
C
C 42 READ(10UDAT,103)
GO TO 12
C
C NOT A COMMAND,CHECK CODE NOT USED BEFORE, GO TO APPROPRIATE
C SECTION (LI = 1,2,3,4 IF LAST COMMAND WAS *COL,*TRA,*INC,*TIP
C RESPECTIVELY)
55 I=LISTEL(COTAB(NP),COTAB,NP)
  IF(I.NE.NP) GO TO 9015
  GO TO (31,32,33,34),LI
C
C COLLECTION CENTROIDS
C
31 READ(10UDAT,102) IDIS(NP),QTY
102 FORMAT(I2,45.0)
  IF(IDIS(NP).LE.0.OR.IDIS(NP).GT.NDIS) GO TO 9016
  OPEN(NP)=1
  SHUT(NP)=NPERS
  MI=MI+1
  IF(MI.GT.35) STOP 1
  DO 11 J=1,NPERS
  A(MI,J)=AFAC(J)*QTY
11 CONTINUE
  WRITE(6,112) ALPHA(MI),NAME
  GO TO 12
C
C TRANSFER STATIONS
C
32 READ(10UDAT,103) MIN,MAX,CSTIN,I0,IS
103 FORMAT(3F5.0,2I2)
  IF(I0.EQ.0) I0=1
  IF(IS.EQ.0.OR.IS.GT.NPERS) IS=NPERS
  OPEN(NP)=I0
  SHUT(NP)=IS
  IDIS(NP)=0
  MJ=MJ+1
  IF(MJ.GT.10) STOP 2
  IF(I0.GT.IS) GO TO 10
  DO 13 J=I0,IS
  CJ(MJ,J)=CSTIN*CXFAC(J)
  Q(MJ,J)=MAX

```



```

R(MJ,J)=MIN
13 CONTINUE
WRITE(6,112) ALPHA(MJ),NAME
112 FORMAT(' *',A1,1X,5A8)
GO TO 12
C
C
C INCINERATORS
13 READ(10,104) MIN,MAX,CSTIN,IO,IS,DT,GT
124 FORMAT(3F5.0,2I2,2F5.0)
IF(10.EQ.0) IO=1
IF(15.EQ.0.OR.15.GT.NPERS) IS=NPERS
OPEN(NP)=IO
SHUT(NP)=IS
IDIS(NP)=-1
MK=MK+1
IF(MK.GT.20) STOP 3
D(MK)=DT
G(MK)=GT
IF(10.GT.IS) GO TO 12
DO 15 J=10,IS
B(MK,J)=MAX
E(MK,J)=MIN
C(MK,J)=CSTIN*CIFAC(J)
15 CONTINUE
WRITE(6,112) ALPHA(MK),NAME
GO TO 12
C
C
C LANDFILL SITES
134 READ(10,105) QTY,CSTIN,IO,IS
125 FORMAT(2F5.0,2I2)
IF(10.EQ.0) IO=1
IO=NINT(QTY)
ML=ML+1
IF(ML.GT.20) STOP 4
IF(15.GT.0.AND.15.LE.NPERS) GO TO 17
IS=NPERS
FILSIT(ML)=.FALSE.
GO TO 18
17 FILSIT(ML)=.TRUE.
15 OPEN(NP)=IO
SHUT(NP)=IS
IDIS(NP)=-2
IF(10.GT.IS) GO TO 12
DO 19 J=10,IS
CL(ML,J)=CSTIN*CTFAC(J)
19 CONTINUE
U(ML)=QTY
WRITE(6,112) ALPHA(ML),NAME
C
12 CONTINUE
NP=151
READ(10,101) COMAND
I=LISTEL(COMAND,COMTAB,6)
IF(1.NE.5) GO TO 9006
C
C
C ROUTES BETWEEN POINTS
52 LASTI=0
NP=NP-1
DO 63 I=1,NP
LINKED(I)=.FALSE.
63 CONTINUE
MS=MI+MJ
MM=MS+MK
ASSIGN 26 TO LABEL
C
C
20 READ(10,21) FROMCO,(TOCO(J),TIME(J),J=1,5)
21 FORMAT(A4,1X,6(A4,F6.0))

```

```

I=LISTEL(FROMCO,COTAB,7)
IF(I.EQ.0) GO TO 29
IF(I.EQ.7) IF(LASTI) 20,9013,25
IF(I.NE.6) GO TO 9005
IF(LASTI.EQ.0) GO TO 9013
ASSIGN 59 TO LABEL
GO TO 120
C
NEW SOURCE CODE
29 I=LISTEL(FROMCO,COTAB,NP)
IF(I.NE.0) GO TO 43
I=LISTEL(FROMCO,EXTAB,NX)
IF(I.EQ.0) GO TO 9009
I=-1
43 IF(I.EQ.LASTI) GO TO 25
IF(IDIS(I).LT.-1) GO TO 9011
IF(LASTI.EQ.0) GO TO 26
IF(LINKED(I)) GO TO 9014
C
CREATE ARCS FROM LASTI
C
(LAST LINE READ HAS NEW SOURCE CODE, SO THERE ARE NO MORE
C
ARCS FROM POINT LASTI)
C
120 IO=OPEN(LASTI)
IS=SHUT(LASTI)
IF(IDIS(LASTI)) 240,220,200
C
200 DO 20 J=IO,IS
DO 20 K=1,NR
L=PTO(K)
IF(OPEN(L).GT.J.OR.SHUT(L).LT.J) GO TO 23
CIX(LASTI,L-MI,J)=LTIM(K)*CCUFAC(J)
23 CONTINUE
22 CONTINUE
GO TO LABEL,(25,59)
C
220 DO 220 J=IO,IS
DO 220 K=1,NR
L=PTO(K)
IF(OPEN(L).GT.J.OR.SHUT(L).LT.J) GO TO 223
CJX(LASTI-MI,L-MS,J)=LTIM(K)*CTUFAC(J)
223 CONTINUE
222 CONTINUE
GO TO LABEL,(26,59)
C
240 DO 400 J=IO,IS
DO 400 K=1,NR
L=PTO(K)
IF(OPEN(L).GT.J.OR.SHUT(L).LT.J) GO TO 401
CKX(LASTI-MS,L-MM,J)=LTIM(K)*CRUFAC(J)
401 CONTINUE
400 CONTINUE
GO TO LABEL,(26,59)
C
DECODE DATA INTO PTO,LTIM
C
25 LASTI=I
IF(I.LT.0) GO TO 20
LINKED(I)=.TRUE.
NR=0
25 DO 27 J=1,5
C
SCAN INPUT LINE, IGNORE BLANK CODES
K=LISTEL(TOCC(J),COMTAB(7),1)
IF(K.EQ.1) GO TO 27
K=LISTEL(TOCC(J),EXTAB,NX)
IF(K.NE.0) GO TO 27
K=LISTEL(TOCC(J),COTAB,NP)
IF(K.EQ.0) GO TO 9010
IF(K.EQ.LASTI) GO TO 9012
NR=NR+1
IF(NR.GT.50) GO TO 9017
PTO(NR)=K

```

```

      LTIME(NR)=TIME(J)
27  CONTINUE
      GO TO 20
C
C      *DIS READ - CHECK FOR MISSING ROUTES.
C
59  CALL RLEASE( IOUDAT )
      DO 81 I=1,NP
      IF( IDIS(I).LT.-1 ) GO TO 82
      IF( .NOT.LINKED(I) ) GO TO 9018
81  CONTINUE
C
82  MD=MJ+MK+ML
      DO 85 I=1,MI
      DO 85 K=1,NPERS
      DO 86 J=1,MD
      IF( CIX(I,J,K).LE.1.E25 ) GO TO 85
85  CONTINUE
      WRITE( IOULOG,97 ) COTAB(I),K
87  FORMAT( ' SOURCE ',A4, ' HAS NO DISPOSAL ROUTES IN PERIOD',I2 )
90  CONTINUE
      MD=MK+ML
      DO 185 J=1,MJ
      JJ=MI+J
      IO=OPEN(JJ)
      IS=SHUT(JJ)
      DO 185 L=1,IS
      DO 186 K=1,MD
      IF( CJK(J,K,L).LE.1.E25 ) GO TO 185
185  CONTINUE
      WRITE( IOULOG,97 ) COTAB(JJ),L
180  CONTINUE
      DO 285 K=1,MK
      KK=MS+K
      IO=OPEN(KK)
      IS=SHUT(KK)
      DO 285 I=1,IS
      DO 286 L=1,ML
      IF( CKX(K,L,I).LE.1.E25 ) GO TO 285
285  CONTINUE
      WRITE( IOULOG,97 ) COTAB(KK),I
285  CONTINUE
C
      CALL WRIMTX( CIX,CJX,CKX,CJ,CK,CL,D,G,A,Q,R,B,E,U,FILSIT,
      1 MI,MJ,MK,ML,NPERS,SIGC,SIGR,LENP )
90  STOP
C
C      ERROR MESSAGES
C
9001 WRITE( IOULOG,9101 )
9101 FORMAT( ' 174 ERROR IN PERIODS ' )
      GO TO 9999
9002 WRITE( IOULOG,9102 )
9102 FORMAT( ' 26H WRONG NUMBER OF DISTRICTS ' )
      GO TO 9999
9003 WRITE( IOULOG,9103 )
9103 FORMAT( ' 26H DISTRICT WRONGLY NUMBERED ' )
      GO TO 9999
9004 WRITE( IOULOG,9104 )
9104 FORMAT( ' 184 TOO MANY COMMENTS ' )
      GO TO 9999
9005 WRITE( IOULOG,9105 ) COTAB(I)
9105 FORMAT( ' 24H COMMAND OUT OF ORDER - ',A4 )
      GO TO 9999
9006 WRITE( IOULOG,9106 )
9106 FORMAT( ' 16H TOO MANY POINTS ' )
      GO TO 9999
9007 WRITE( IOULOG,9107 )
9107 FORMAT( ' 15H TOO MANY NODES ' )
      GO TO 9999
9008 WRITE( IOULOG,9108 )

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```
9109 FORMAT(14H TOO MANY ARCS )
      GO TO 9999
9109 WRITE(IOULOG,9109) FROMCO
9109 FORMAT(26H UNRECOGNISED SOURCE CODE - ,A4)
      GO TO 9999
9110 WRITE(IOULOG,9110) COTAB(LASTI),TOCO(J)
9110 FORMAT(33H UNRECOGNISED DESTINATION CODE - ,A4,4H... ,A4)
      GO TO 9999
9111 WRITE(IOULOG,9111) FROMCO
9111 FORMAT(23H INVALID SOURCE CODE - ,A4)
      GO TO 9999
9112 WRITE(IOULOG,9112) TOCO(J)
9112 FORMAT( 24H SOURCE = DESTINATION - ,A4)
      GO TO 9999
9113 WRITE(IOULOG,9113)
9113 FORMAT(20H ROUTES OUT OF ORDER )
      GO TO 9999
9114 WRITE(IOULOG,9114) FROMCO
9114 FORMAT(24H REPEATED SOURCE CODE - ,A4)
      GO TO 9999
9115 WRITE(IOULOG,9115) COTAB(I)
9115 FORMAT(19H CODE DUPLICATED - ,A4)
      GO TO 9999
9116 WRITE(IOULOG,9116) COTAB(NP)
9116 FORMAT(25H INVALID DISTRICT NO. FOR ,A4)
      GO TO 9999
9117 WRITE(IOULOG,9117) COTAB(LASTI)
9117 FORMAT(22H TOO MANY ROUTES FROM ,A4)
      GO TO 9999
9118 WRITE(IOULOG,9118) COTAB(I)
9118 FORMAT(19H NO ROUTES FROM ,A4)
C
9999 STOP ??
C
      ERROR EXIT
      END
```

```
      SUBROUTINE GROWTH(PCTG,PCTD,LENP,FAC,NPERS)
C
C   CALCULATE TIME FACTORS, FOR PCTG PERCENT COMPOUND GROWTH
C   AND PCTD PERCENT DISCOUNT
C
      REAL LENP(NPERS),FAC(NPERS)
      TEMP=(1.0+0.01*PCTG)/(1.0+0.01*PCTD)
      IF(ABS(TEMP-1.0).LT.1.0E-5) GO TO 4
      TAU=1.0/ALOG(TEMP)
      T1=0.0
      EXPT1=1.0
      DO 5 I=1,NPERS
      T2=T1+LENP(I)/TAU
      EXPT2=EXP(T2)
      FAC(I)=(EXPT2-EXPT1)*TAU
      T1=T2
      EXPT1=EXPT2
5   CONTINUE
      GO TO 1
C
C   4 DO 6 I=1,NPERS
      FAC(I)=LENP(I)
6   CONTINUE
C
1   RETURN
      END
```

```
FUNCTION LISTEL(A,B,N)
C
C LOCATION OF 4-CHARACTER TEXT A IN LIST B
C RETURNS 0 IF A NOT FOUND
C *** MACHINE DEPENDENT *** - THIS IS 1900 VERSION
DIMENSION B(N)
IF(N.LT.1) GO TO 2
DO 1 LISTEL=1,N
I=4
CALL COMP(I,A,1,B(LISTEL),1)
IF(I.EQ.4) GO TO 3
1 CONTINUE
2 LISTEL=0
3 RETURN
END
```

```
BLOCK DATA
INTEGER ALPHA(35),SPACE
COMMON /ALPHA/ ALPHA,SPACE
DATA ALPHA/'A','B','C','D','E','F','G','H','I','J','K','L','M',
1 'N','O','P','Q','R','S','T','U','V','W','X','Y','Z',
2 '1','2','3','4','5','6','7','8','9'/
DATA SPACE/' '/
END
```

```

SUBROUTINE WRINTX(CIX,CJX,CKX,CJ,CK,CL,D,G,A,Q,R,B,E,U,FILL,
1 MI,MJ,MK,ML,MT,SIGC,SIGR,LENP)
REAL CIX(35,S0,9),DC(20),AC(35,9),RC(10,9),UC(20),QC(10,9),BC(20,9),
1 EC(20,9),CK(20,9),CL(20,9),GC(20),CJX(10,40,9),CKX(20,20,9),
2 CJ(10,9),KWOR,LENP(9)
LOGICAL FILL(20),LLJ(10,9),LLK(20,9)
INTEGER T,ALPHA(35),PLUS,MINUS,NOUGHT,SPACE,ALI,ALJ,ALK,ALL,ALM
COMMON /ALPHA/ ALPHA,SPACE
DATA NIL/0/,ONE/1.0/,ZERO/0.0/,ONEM/ -1.0/
DATA PLUS,MINUS,NOUGHT/'+', '-', '0'/
DATA LLJ,LLK/270*.FALSE./
1 FORMAT(7X,4A1,I1,2X,2A1,I1,3X,F12.6)
4 FORMAT(6X,'RHS ',2A1,I1,3X,F12.6)
7 FORMAT(6X,'1',5X,A1,1X,2A1,I1)
8 FORMAT(6X,'RHR ',2A1,I1,3X,F12.6)
C
C COLUMN NAME FORMAT - IJKLTS (T INTEGER,OTHERS ALPHA)
C
C ROW NAME FORMAT - SAQTSS
C WHERE S=SPACE,Q=I,J,K OR L
C AND A = A FOR ARISING
C I,J FOR INCINERATORS
C X,Y FOR TRANSFER
C T FOR TIPS
C C FOR COST
C
MM=MJ+MK
NROW=1
NCOL=2
C
WRITE(6,6)
6 FORMAT(' ROW ID')
C
WRITE(6,7) ALPHA(26),ALPHA(3),ALPHA(1),NIL
DO 39 T=1,MT
DO 30 I=1,MI
IF(A(I,T).GT.1.E25) GO TO 30
WRITE(6,7) NOUGHT,ALPHA(1),ALPHA(I),T
NROW=NROW+1
30 CONTINUE
DO 31 J=1,MJ
IF(Q(J,T).GT.1.E25) GO TO 31
NROW=NROW+2
WRITE(6,7) NOUGHT,ALPHA(25),ALPHA(J),T
TEMP=R(J,T)/Q(J,T)
IF(TEMP.GT.0.995) GO TO 35
WRITE(6,7) PLUS,ALPHA(24),ALPHA(J),T
IF(TEMP.LT.0.005) GO TO 37
GO TO 31
35 WRITE(6,7) NOUGHT,ALPHA(24),ALPHA(J),T
37 LLJ(J,T)=.TRUE.
31 CONTINUE
DO 32 K=1,MK
IF(B(K,T).GT.1.E25) GO TO 32
NROW=NROW+2
WRITE(6,7) NOUGHT,ALPHA(10),ALPHA(K),T
TEMP=E(K,T)/B(K,T)
IF(TEMP.GT.0.995) GO TO 36
WRITE(6,7) PLUS,ALPHA(9),ALPHA(K),T
IF(TEMP.LT.0.005) GO TO 38
GO TO 32
36 WRITE(6,7) NOUGHT,ALPHA(9),ALPHA(K),T
38 LLK(K,T)=.TRUE.
32 CONTINUE
39 CONTINUE
DO 33 L=1,ML
IF(U(L).GT.1.E25) STOP 76
NROW=NROW+1
IF(FILL(L)) GO TO 34
WRITE(6,7) PLUS,ALPHA(20),ALPHA(L),NIL
GO TO 33

```



```

34 WRITE(6,7) NOUGHT,ALPHA(20),ALPHA(L),NIL
33 CONTINUE
C
NELEM=NROW
WRITE(6,2)
2 FORMAT(' MATRIX')
DO 19 T=1,MT
C
DO 14 I=1,MI
CALL COPY(1,ALI,1,ALPHA(I),1)
DO 14 J=1,MJ
COST=CIX(I,J,T)+CJK(J,T)
IF(COST.GT.1.E25) GO TO 14
CALL COPY(1,ALJ,1,ALPHA(J),1)
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) ALI,ALJ,SPACE,SPACE,T,ALPHA(1),ALI,T,ONE
WRITE(6,1) ALI,ALJ,SPACE,SPACE,T,ALPHA(25),ALJ,T,ONE
WRITE(6,1) ALI,ALJ,SPACE,SPACE,T,ALPHA(24),ALJ,T,ONE
WRITE(6,1) ALI,ALJ,SPACE,SPACE,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+4
14 CONTINUE
C
DO 10 J=1,MJ
CALL COPY(1,ALJ,1,ALPHA(J),1)
DO 10 K=1,MK
COSK=CJX(J,K,T)
IF(COSK.GT.1.E25) GO TO 10
PP=D(K)
P=1.0-PP
VOLC=SIGC*PP
VOLR=G(K)*P
VOLCT=VOLC*LENP(T)
COSK=P*COSK+CK(K,T)
CALL COPY(1,ALK,1,ALPHA(K),1)
DO 10 L=1,ML
COSL=CJX(J,MK+L,T)
IF(COSL.GT.1.E25) GO TO 10
COST=PP*COSL+CL(L,T)*VOLC+COSK
CALL COPY(1,ALL,1,ALPHA(L),1)
IF(COST.GT.1.E25) GO TO 10
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) SPACE,ALJ,ALK,ALL,T,ALPHA(25),ALJ,T,ONEMI
WRITE(6,1) SPACE,ALJ,ALK,ALL,T,ALPHA(10),ALK,T,VOLR
WRITE(6,1) SPACE,ALJ,ALK,ALL,T,ALPHA(9),ALK,T,ONE
WRITE(6,1) SPACE,ALJ,ALK,ALL,T,ALPHA(20),ALL,NIL,VOLCT
WRITE(6,1) SPACE,ALJ,ALK,ALL,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+5
10 CONTINUE
C
DO 11 I=1,MI
CALL COPY(1,ALI,1,ALPHA(I),1)
DO 11 K=1,MK
COSK=CIX(I,MJ+K,T)
IF(COSK.GT.1.E25) GO TO 11
PP=D(K)
P=1.0-PP
VOLC=SIGC*PP
VOLR=P*G(K)
VOLCT=VOLC*LENP(T)
CALL COPY(1,ALK,1,ALPHA(K),1)
DO 11 L=1,ML
COSL=CIX(I,MM+L,T)
IF(COSL.GT.1.E25) GO TO 11
COST=AMAX1(COSK,COSL)+CK(K,T)+CL(L,T)*VOLC
CALL COPY(1,ALL,1,ALPHA(L),1)
IF(COST.GT.1.E25) GO TO 11
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) ALI,SPACE,ALK,ALL,T,ALPHA(1),ALI,T,ONE

```

```

WRITE(6,1) ALI,SPACE,ALK,ALL,T,ALPHA(10),ALK,T,UOLR
WRITE(6,1) ALI,SPACE,ALK,ALL,T,ALPHA(9),ALK,T,ONE
WRITE(6,1) ALI,SPACE,ALK,ALL,T,ALPHA(20),ALL,NIL,UOLCT
WRITE(6,1) ALI,SPACE,ALK,ALL,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+S
11 CONTINUE
C
VOLCT=SIGC*LENP(T)
DO 12 J=1,MJ
CALL COPY(1,ALJ,1,ALPHA(J),1)
DO 12 L=1,ML
COST=CJX(J,MK+L,T)+SIGC*CL(L,T)
IF(COST.GT.1.E25) GO TO 12
CALL COPY(1,ALL,1,ALPHA(L),1)
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) SPACE,ALJ,SPACE,ALL,T,ALPHA(25),ALJ,T,ONEMI
WRITE(6,1) SPACE,ALJ,SPACE,ALL,T,ALPHA(20),ALL,NIL,UOLCT
WRITE(6,1) SPACE,ALJ,SPACE,ALL,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+3
12 CONTINUE
C
DO 13 I=1,MI
CALL COPY(1,ALI,1,ALPHA(I),1)
DO 13 L=1,ML
CALL COPY(1,ALL,1,ALPHA(L),1)
COST=CIX(I,MM+L,T)+SIGC*CL(L,T)
IF(COST.GT.1.E25) GO TO 13
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) ALI,SPACE,SPACE,ALL,T,ALPHA(1),ALI,T,ONE
WRITE(6,1) ALI,SPACE,SPACE,ALL,T,ALPHA(20),ALL,NIL,UOLCT
WRITE(6,1) ALI,SPACE,SPACE,ALL,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+3
13 CONTINUE
C
VOLRT=SIGR*LENP(T)
DO 15 K=1,MK
CALL COPY(1,ALK,1,ALPHA(K),1)
DO 15 L=1,ML
COST=CKX(K,L,T)+CL(L,T)*SIGR
IF(COST.GT.1.E25) GO TO 15
CALL COPY(1,ALL,1,ALPHA(L),1)
NCOL=NCOL+1
COST=COST*0.01
WRITE(6,1) SPACE,SPACE,ALK,ALL,T,ALPHA(10),ALK,T,ONEMI
WRITE(6,1) SPACE,SPACE,ALK,ALL,T,ALPHA(20),ALL,NIL,UOLRT
WRITE(6,1) SPACE,SPACE,ALK,ALL,T,ALPHA(3),ALPHA(1),NIL,COST
NELEM=NELEM+3
15 CONTINUE
C
19 CONTINUE
WRITE(6,3)
3 FORMAT(' FIRSTB' )
C
DO 20 T=1,MT
DO 20 I=1,MI
IF(A(I,T).GT.1.E25) GO TO 20
WRITE(6,4) ALPHA(1),ALPHA(I),T,A(I,T)
20 CONTINUE
DO 21 J=1,MJ
IF(Q(J,T).GT.1.E25) GO TO 21
WRITE(6,4) ALPHA(25),ALPHA(J),T,ZERO
WRITE(6,4) ALPHA(24),ALPHA(J),T,Q(J,T)
21 CONTINUE
DO 22 K=1,MK
IF(B(K,T).GT.1.E25) GO TO 22
WRITE(6,4) ALPHA(10),ALPHA(K),T,ZERO
WRITE(6,4) ALPHA(9),ALPHA(K),T,B(K,T)
22 CONTINUE
29 CONTINUE

```

```

      DO 23 L=1,ML
      WRITE(6,4) ALPHAK(20),ALPHAK(L),NIL,U(L)
23  CONTINUE
C
      WRITE(6,101)
101  FORMAT(' RANGE')
      DO 28 T=1,MT
      DO 24 J=1,MJ
      IF(Q(J,T).GT.1.E25) GO TO 24
      IF(LLJ(J,T)) GO TO 24
      DIFF=Q(J,T)-R(J,T)
      WRITE(6,8) ALPHAK(24),ALPHAK(J),T,DIFF
      NELEM=NELEM+1
24  CONTINUE
      DO 25 K=1,MK
      IF(B(K,T).GT.1.E25) GO TO 25
      IF(LLK(K,T)) GO TO 25
      DIFF=B(K,T)-E(K,T)
      WRITE(6,8) ALPHAK(9),ALPHAK(K),T,DIFF
      NELEM=NELEM+1
25  CONTINUE
28  CONTINUE
C
      KWOR=(10.0*FLOAT(NROW)+11.0*FLOAT(NCOL)+FLOAT(NELEM))/320.0
      WRITE(2,90) NROW,NCOL,NELEM,KWOR
90  FORMAT(I10,' ROWS',I10,' COLUMNS',I10,' NON-ZERO ELEMENTS' /
      1 1X,F6.1,' KWORDS REQUIRED FOR PROBLEM FILE')
      IF(KWOR.GT.250.0) STOP 'TOO BIG'
      WRITE(6,5)
5  FORMAT(' EOF')
      RETURN
      END

```

APPENDIX G

LISTING OF THE DATA USED FOR THE TRANSHIPMENT

WITH GAINS PROGRAM

3 7 10.0 -1.0 0.0 4.2 0.0 1.28 0.0 1.28 0.0 0.0 0.0 2.5 1.0
 2.0 4.0 4.0

ANNUAL AVERAGES DATA

COSTS IN POUNDS, QUANTITIES IN TONNES
 2.5 CU.METRES PER TONNE ASSUMED IN LANDFILL

*COL

CCOU COVENTRY DISTRICT

2 914

CSON SOLIHULL N. DISTRICT

5 207

CSOE SOLIHULL S.E. DISTRICT

5 33

CSOW SOLIHULL S.W. DISTRICT

5 150

CLIF LIFFORD DISTRICT

1 528

CTYS TYSELEY DISTRICT

1 347

CCBS CASTLE BROMWICH S. DISTRICT

1 481

CCBN CASTLE BROMWICH N. DISTRICT

1 43

CSNW SANDWELL N.W. DISTRICT

4 142

CSSW SANDWELL S.W. DISTRICT

4 168

CSSE SANDWELL S.E. DISTRICT

4 66

CSNE SANDWELL N.E. DISTRICT

4 282

CRPK ROTTOM PARK DISTRICT

1 298

CMON MONTAGUE ST. DISTRICT

1 395

CPER PERRY BARR DISTRICT

1 482

CWOL WOLVERHAMPTON DISTRICT

7 633

CWNE WALSALL N.E. DISTRICT

6 34

CWSE WALSALL S.E. DISTRICT

6 68

CWW WALSALL W. DISTRICT

6 573

CSUT SUTTON COLDFIELD DISTRICT

1 178

CDN DUDLEY N. DISTRICT

3 370

CDSE DUDLEY S.E. DISTRICT

3 97

CDSW DUDLEY S.W. DISTRICT

3 115

*TRA

XRPK ROTTOM PARK ST. WORKS

0 500 19.0

XSOL SOLIHULL WORKS

0 200 19.0

XW/S WALSALL/SANDWELL WORKS

0 500 19.0 2

XBEN BENTLEY LANE TRANSFER STATION

0 120022.S1 3

XBAR BARNFIELD RD. TRANSFER STATION

0 120022.S1 1 1

*INC

IPER PERRY BARR WORKS

1076 1196 156 0 0 0.150.335

ICBR CASTLE BROMWICH WORKS

543 603 111 0 0 0.150.335

ILIF LIFFORD WORKS

477 530 58 0 0 0.150.335

ISUT SUTTON COLDFIELD WORKS

168 187 350 0 0 0.150.335
 ICO2 COVENTRY WORKS (2 STREAM)
 1000 1600 100 0 0 0.150.335
 IDUD DUDLEY WORKS
 632 702 179 0 0 0.150.335
 IWOL WOLVERHAMPTON WORKS
 927 1030 73 0 0 0.150.335
 IIMI I.M.I. PLANT
 300 375 0.0 0 0 0.50 0.00
 ITYN NEW TYSELEY WORKS
 1000 1500 100 0 0 0.150.335
 ICO3 COVENTRY WORKS (3RD STREAM)
 600 600 100 0 0 0.150.335

*TIP

IPAK PACKINGTON LANDFILL SITE

S0000 60

TBEL BENTLEY LANE SITE

915 35

TTIU TIVIDALE SITE

8880 35 2

TMUK MUCKLOW HILL SITE

704 35

TFAR BARNFIELD RD. SITE

497 35 1 1

THAY HAY LANE SITE

1095 35

TOAK OAK FARM SITE

2700 2

TFAR LONG HAUL SITE

20000 35

TBLU BLUE ROCK QUARRY

2450 35

TALS ALLSOPP'S QUARRY

11370 35 2

TBOO BOOTH'S LANE SITE

8200 35 2

TBIR BIRCH COPPICE SITE

2320 35 2

TSPE SPEEDWELL SITE

985 35

TMAR MARLBROOK SITE

560 35

*ROU

XRPK

	ITYN	57.8IPER	38.6ICBR	75.2ILIF	53.7		
	TBOO	45.6TALS	44.4TBIR	93.0			
	THAY	88.8TMUK	43.4TBEL	78.8			
	ICO2	134.7ICO3	134.7IIMI	38.6			
	ISUT	78.8TFAR	183.0TTIU	54.7			
	TOAK	112.5					
XSOL	ICO3	80.0ICO2	80.0TFAR	112.4ICBR	71.0ISUT	78.4ILIF	42.6
	IPAK	49.6					
	ITYN	39.0					
XW/S	ICO3	114.8ICO2	114.8IPER	30.0IWOL	36.0IDUD	59.2	
	TALS	54.4TBOO	40.0TBIR	63.4TFAR	36.8		
	TBEL	22.2					
	ITYN	63.4ICBR	57.6ISUT	57.6			
	ILIF	91.2TMUK	54.0TFAR	136.4IIMI	30.0		
	TTIU	40.8TOAK	70.4				
XBEN	IWOL	40.8IDUD	84.6ISUT	69.2IPER	47.0ICO2	132.0ICO3	132.0
	ITYN	95.4ICBR	70.0TMUK	63.4			
	TFAR	150.8IIMI	47.0				
	TOAK	81.6TTIU	58.4				
XBAR	IPER	58.8IIMI	58.8				
	IDUD	24.8IWOL	36.6TMUK	44.8			
	ISUT	77.8ICO2	106.8ICO3	106.8			
	ITYN	85.2ICBR	86.2				
	TFAR	157.0TOAK	52.2TTIU	24.0			
CCOU	ICO3	35.2ICO2	35.2TFAR	63.6IPAK	55.2THAY	91.0	

CSON	IPAK	39.4	ICBR	26.0	ISUT	34.6			
	ITYN	43.0	TFAR	68.8					
	XSOL	58.0	IC02	72.0	IC03	72.0			
CDOE	IPAK	39.6	THAY	45.0	IC02	62.4	IC03	62.4	XSOL 45.0
CDOH	THAY	22.6							TFAR 37.2
	ITYN	37.4	ILIF	55.8	IC02	80.0	IC03	80.0	
	XSOL	22.6	IPAK	42.0					
CLIF	ILIF	23.2	XRPK	47.2					
	ITYN	52.8	TBLU	47.4	TALS	58.0			
	THAY	63.6							
	XSOL	63.6	TMUK	52.0	IC02	138.0	IC03	138.0	
CTYS	IC02	96.6	IC03	96.6	XRPK	48.8			
	ITYN	23.0							
	THAY	43.0							
	ICBR	50.0	ILIF	44.0	XSOL	43.0			
	IPAK	54.6	TMUK	63.2	TBOO	66.0			
CCBS	IPER	41.6	ISUT	28.2	IPAK	42.6	THAY	65.0	ICBR 21.2
	ITYN	31.0							
	XSOL	65.0							
CCBN	IPER	23.2	ICBR	31.0	ISUT	26.8	XRPK	46.6	TBEL 63.8
	TMUK	76.8	IPAK	68.8	XBEN	63.8	TBOO	34.4	
CSNW	IPER	48.6	IDUD	32.8	XW/S	22.6	XRPK	45.6	TTIU 18.6
	TBOO	37.8	TALS	39.2	TBLU	29.6	TBAR	18.4	
	TOAK	64.2	IWOL	40.4	TMUK	35.8	XBAR	18.4	
	TBEL	39.8	XBEN	39.8					
CSSW	TMUK	24.0	XRPK	51.6	XW/S	49.6	TTIU	37.6	TOAK 79.2
	XBAR	33.6	TBLU	16.8	TBAR	33.6	IPER	61.4	ITYN 73.4
	TALS	21.0							
CSSE	XBAR	35.2							
	XRPK	28.8	TMUK	32.0	IPER	41.0	TTIU	31.2	
	TALS	27.2	TBLU	26.4	TBAR	35.2	ITYN	51.4	
CSNE	TBEL	39.8	XBEN	39.8	IPER	33.0	IDUD	49.6	XRPK 35.4
	TALS	42.0	TBOO	23.4	TBLU	31.4	TBAR	36.8	
	TMUK	43.2	XBAR	36.8					
	XW/S	22.2	TTIU	28.6	TOAK	75.0			
CRPK	XRPK	19.6	TMUK	37.4	IPER	44.4			
	ITYN	48.8							
	TALS	44.4							
	ILIF	34.6							
CNON	TMUK	67.8	XRPK	34.8					
	ITYN	29.0	TBOO	54.4	TBLU	58.6	TALS	70.0	IPAK 76.0
	IPER	33.6							
	ICBR	46.4	ILIF	50.4	THAY	70.4	XSOL	70.4	TBEL 64.4
CPER	IPER	15.8	TBEL	51.8	TMUK	57.6	XBEN	51.8	XRPK 31.8
	TBOO	21.0	TALS	54.6					
	ITYN	53.6							
	ICBR	44.4	ISUT	45.8					
CWOL	IWOL	20.8	TBEL	41.6	XW/S	52.0			
	TTIU	56.4	TOAK	51.0	XBAR	43.0			
	XBEN	41.6	TBLU	49.2	TALS	66.0	TBAR	43.0	TBIR 63.4
CWNE	XBEN	41.0	XW/S	52.0	TBEL	41.0			
	TBOO	42.6	TBIR	17.6	IPER	63.4	IWOL	71.4	
CWSE	IPER	38.8	XW/S	40.2	TBEL	41.4	XBEN	41.4	
	TBOO	21.0	TBIR	44.0	ICBR	51.4			
CWW	XBEN	27.2	XW/S	24.0	IPER	41.8	XRPK	59.4	TFAR 145.4
	TBOO	34.0	TALS	58.4	TBIR	42.0			
	TBEL	27.2	IWOL	48.8					
CSUT	ISUT	32.4	ICBR	41.6	IPER	44.4	TFAR	97.6	TBEL 76.4
	IPAK	61.4	XBEN	76.4	TBOO	33.0	TBIR	60.6	
CDM	XBAR	36.0	IWOL	50.0	TBLU	31.4	TBAR	36.0	
	TTIU	39.2	TOAK	24.0	XRPK	76.8	ILIF	92.4	IPER 83.2
	IDUD	22.6	TALS	37.4					
CDOE	TMUK	23.0	IDUD	30.4	XRPK	56.8	ILIF	76.0	IPER 75.6
	TALS	29.6	TBLU	31.4					TOAK 64.2
CDSW	TOAK	48.0	TMUK	41.6	IDUD	41.6	TALS	49.6	
	IPER	52.4	TBOO	24.0	TBLU	49.4	TALS	60.0	
ICBR	IPAK	49.6	TSPE	42.4	TBEL	69.2	TBOO	48.0	
ILIF	THAY	57.4	TMAR	47.4	TSPE	56.8	TBLU	54.6	TALS 65.4
ITYN	TSPE	6.0	THAY	48.0	IPAK	57.6	TBOO	61.4	TMAR 86.6

ISUT	IPAK	57.2TSPE	53.6TBEL	70.0TB00	48.6TBIR	86.6
IWOL	TBEL	42.4TBLU	59.4TALS	69.4TBIR	63.4	
IDUD	TMUK	38.4TBLU	26.0TALS	19.2TB00	64.4	
IC02	THAY	108.0IPAK	76.4			
IC03	THAY	108.0IPAK	76.4			
IIMI	IPAK	0.0				

*DIS

- 1 BIRMINGHAM
- 2 COVENTRY
- 3 DUDLEY
- 4 SANDWELL
- 5 SOLIHULL
- 6 WALSALL
- 7 WOLVERHAMPTON

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