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CHICAGO AIR POLLUTION SYSTEMS ANALYSIS PROGRAM

LONG-RANGE PLANNING IN AIR RESOURCE MANAGEMENT

by

A. S. Cohen, E. J. Croke, A. Hurter,
J. E. Norco, and J. J. Roberts

ARGONNE NATIONAL LABORATORY

CHICAGO DEPARTMENT OF ENVIRONMENTAL CONTROL

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

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National Air Pollution Control Administration

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Center for Environmental Studies

January 1971

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FOREWORD

(E. J. Croke, Program Director)

The City of Chicago Air Pollution Systems Analysis Study discussed in this report represents a joint effort conducted and funded by the Atomic Energy Commission, the Department of Health, Education, and Welfare,* and the Chicago Department of Air Pollution Control.**

Program direction, system analysis, and computer programming are provided by the Argonne National Laboratory. Meteorology studies and computer model development are performed by Argonne and the National Center for Air Pollution Control, Cincinnati, Ohio. The Chicago Department of Air Pollution Control supplies emission and air quality data for the atmospheric dispersion studies.

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**Early in 1970, the City of Chicago reorganized the Department of Air Pollution Control. It now functions as a part of the Department of Environmental Control.

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The objectives of this program were based on the fact that comprehensive urban air resource management involves interrelationships among technical, economic, and administrative factors. These relationships must be taken into account in the development of effective air-pollution control strategies. If an air quality control region, whether of urban or interstate dimensions, is not treated as a unified system of interrelated components, then any localized or partial air-management strategies developed are likely to be suboptimal. That is, either the desired air quality goals will not be attained, or unacceptable economic and operational penalties will be paid in the achievement of the established air quality standards. The Chicago project was therefore oriented around the use of the methodologies of system analysis to develop effective air-pollution incident-control strategies and long-range air quality control plans for urban areas.

The system-analysis program was designed to attain three primary objectives:

1. The development of a computerized methodology for 12-to-24-hr advance prediction of ambient sulfur dioxide concentrations produced by the combustion of coal and oil in residential, commercial, and industrial sources and power plants. Such a forecasting scheme would make it possible to formulate effective incident-control strategies by providing the lead-time necessary to implement air-pollution-alert and emission-control plans. This effort is centered primarily on analytical and experimental studies necessary for the development of a source-oriented atmospheric-diffusion model.
2. The development of optimal air-pollution incident-control strategies. A matrix of practical, air-pollution incident-control plans must be based on detailed analyses of the operational and economic constraints imposed on emission control of various types of pollution-producing processes, on maximum exploitation of air-pollution control resources such as natural gas, and on cost-effectiveness studies of alternative controls strategies. This approach should result in air-pollution incident-control plans which involve the minimum possible disruption of normal operations consistent with the attainment of acceptable air quality standards during an incident.
3. The integration of air-pollution control into the long-range planning for an urban area. This involves a determination of the most effective use of emission-control legislation, zoning ordinances, land-utilization planning, highway routing, etc., to ensure that the urban area will evolve, during the next 10-15 yr, in such a way that no new air-pollution source clusters will be created and that the layout of residential, commercial, and industrial areas and transportation networks will be consistent with the maintenance of acceptable air quality standards. This long-range planning effort involves taking account of population, economic and industrial growth patterns, and interaction with other urban planning

agencies. A critically important aspect of the planning effort involves evaluation of the long-range economic impact of air-pollution control, since it is clearly unfeasible to formulate control plans that would seriously compromise key elements in the economic base of the urban area.

A combination of a computerized, source-oriented, atmospheric, pollution-dispersion model and use of the techniques of operations research are key elements in the long-range planning phase discussed in this report.

The system-analysis studies are conducted on the premise that the results must be generally applicable on a national scale. That is, the City of Chicago serves as a test case or demonstration city for the development of methodologies, techniques, models, and procedures which can be readily applied in other urban areas. Emphasis is therefore placed on the study and solution of air-pollution problems that the Chicago metropolitan area shares with other medium-to-large urban concentrations, rather than on elements that are local and peculiar to Chicago alone.

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ABSTRACT

~~This report is~~ ^a comprehensive documentation of the long-range planning phase of the Chicago Air Pollution Systems Analysis Program ^{is presented}. Air resource management is made an integral part of land-use planning by means of a set of emission-density regulations.

These emission densities define a maximum emission rate per land area unit for each land-use classification, i.e., lb/mi²-hr. Compliance with these emission densities ensures the maintenance of acceptable air quality over time.

Land-use plans are reflected in local zoning ordinances. A systematic statistical procedure for conducting a zoning survey is presented. The results of a zoning survey conducted for the Chicago Metropolitan Air Quality Control Region are also given.

Finally, a model for projecting and displaying future air-pollution levels is formulated. This computerized package includes projection, climatology, and dispersion models. Annual and seasonal projections of sulfur dioxide levels in Chicago are made for the year 1980, assuming a 1.5% limit of sulfur is imposed for all fuels used in Chicago.

(auth)

1. INTRODUCTION

(A. S. Cohen)

Long-range planning in air resource management involves the formation, development, evaluation, and implementation of air-pollution control strategies to ensure the maintenance of acceptable air quality over time. Such strategies must be flexible enough to avoid rapid obsolescence, yet stable enough to provide, for the components of the urban economic system, a base to develop and implement long-range plans.

The popular "per-source" control strategies, which include process-weight, process-heat, fuel-sulfur and ash-content limits, control-device requirements, and stack-height control ordinances, do not, in general, have the properties mentioned above. As an urbanizing region evolves, the pattern and intensity of land use may change drastically. This may result in increased pollution emissions over time, even if control regulations are strictly enforced. Such control regulations will tend to obsolesce and will eventually have to be reformulated.

This inherent obsolescence increases the uncertainty of the long-range planning function for the various economic activities in the control region. Because of the capital expense involved in air-pollution control, an industrial firm will plan its expansion program to ensure that it will comply with control regulations over time. An increase in the uncertainty regarding the severity of these regulations will decrease the probability of making economically sound decisions.

This report describes an approach to the development of implementation plans for stationary sources of SO_2 and particulates based on the integration of air resource management with urban and regional planning. This is achieved through the establishment of well-defined emission rights associated with each parcel of land in the region and a projection of regional development. An atmospheric dispersion model is used to design the required controls. The method ensures that the desired long-range regional air quality goals are attained by implementation plans which have an inherent economic optimality, yet which are not sensitive to detailed inputs required in cost-effectiveness analysis.

This approach requires two essential inputs: a zoning inventory of the region and projections of pollution emissions without control. This report includes a detailed discussion of the procedures and analysis required to develop these inputs and presents the models and display techniques required to project future emissions and air quality. The methodology can be used both for developing optimal emission controls and to estimate the effects "per-source" types of control will have on air quality over time.

The application of the techniques presented in this report is demonstrated, using data supplied by the Chicago Department of Air Pollution Control and municipal and regional planning agencies throughout the Metropolitan Chicago Air Quality Control Region.

2. LAND USE AS AN ORGANIZATIONAL BASIS FOR REGIONAL AIR RESOURCE MANAGEMENT

(E. J. Croke and J. J. Roberts)

2.1 Discussion

Since the Clean Air Act of 1967 was enacted, the national air-pollution control program has focused on the application of the systems analysis methodology to the problem of planning, evaluating, and implementing regional air resource management programs.

The national program includes the development of a taxonomy of air pollutants, the publication of air quality criteria, and the compilation of detailed summaries of the state-of-the-art of emission-control technology for each pollutant. State governments are required to adopt air quality standards and to develop regional "implementation plans" for the control of each of the specified pollutants. The implementation plans submitted by each state to the National Air Pollution Control Administration (NAPCA) for approval includes a statement of the legal authority to enforce emission controls, a set of emission-control regulations, plans for air quality and source surveillance, an episode-control plan, a statement of the resources required by the control agency in order to implement the plan, and a timetable for implementation.

The effectiveness of emission-control regulations for the first set of pollutants to be controlled--sulfur oxides and suspended particulates--is to be evaluated by means of an array of computerized simulation models developed under NAPCA sponsorship. These include atmospheric dispersion, control strategy, control-cost effectiveness, fuel-resource allocation, and cost-benefit models. Although only the first two of these simulation systems are fully operational at present, the others are in an advanced state of development and represent a clear commitment to classical systems-analysis methods for the evaluation of alternatives through the use of mathematical models.

In parallel with the development of systems-analysis techniques, control technology research and the development of extensive source inventories have been in progress. Enforcement methods continue to rely on a corps of smoke watchers and equipment inspectors. Although these efforts are necessary, the tendency in the design of regional implementation plans has been to place dollar figures on control hardware and fuel options and to evaluate possible curbs of emissions from each source or source class. These cost-effectiveness approaches have three major faults:

1. They depend upon cost data which are, for the most part, unobtainable with sufficient detail and accuracy to evaluate alternative strategies. (For example, Jackson et al., 1969, show this to be true for automobile-exhaust controls.)

2. They focus on the city or region of today trying to cope with the complex heterogeneity of source types and potential control methods in the formulative phase of the development of the implementation plans (for example, Frankel, 1969).

3. They focus on details such as refined source inventories and hardware and fuel costs, instead of on present and future regional air quality.

Implementation plan methodologies often are associated with control strategies which are vague and unevenly applied. For example, the approach requiring "maximum possible reduction of emissions" is by nature unclear in the degree of severity implied and will merely result in an inequitable distribution of the economic burden. The concept of "uniform percent reduction of emissions" unfairly burdens the operator of a plant with existing control apparatus. Quotas of allowable pollutant emissions in a given square mile often favor existing polluters by unfairly freezing the development of adjacent vacant lands. At best, these difficulties will be handled by a flood of appeals and subsequent variances; most likely, these fundamental problems will defeat the program, as is already indicated by prevalent pessimism regarding the potential success of the Clean Air Act.

This section describes an approach to the development of implementation plans for stationary sources of SO_2 and particulates based on the integration of air resource management with urban and regional planning. This is achieved through the establishment of well-defined emission rights associated with each parcel of land in the region. The methodology ensures that the desired long-range regional air quality goals are attained by implementation plans which have an inherent economic optimality, yet which are not sensitive to detailed inputs required in a cost-effectiveness analysis. It has the following features, some of which are special to this approach, all of which are required or desirable in a regional plan for the attainment of air quality standards:

1. Ensures long-term maintenance of air quality standards.
2. Tailors emission-control regulations to the character and projected growth of the region and thus conforms to the existing and projected demographic and economic design of the region.
3. Permits regional planners to evaluate revised growth patterns and thus revised emission-control regulations, especially in the development of unincorporated areas.
4. Develops fair and unequivocal regulations.
5. Permits formulation and promulgation of the emission-control regulations before a detailed source inventory is assembled, thus avoiding a one- to two-year delay in enforcement or equivalently providing greater lead time for source operators to achieve compliance.

6. Minimizes economic burden by offering the maximum number of alternatives by which sources can be brought into compliance. (It is not tied to any particular fuel use or control technology.)

7. Incorporates provisions for planned reduction of emissions during infrequent air-pollution incidents.

8. Is integrated with an effective surveillance system to ensure compliance with routine and emergency emission-control regulations.

Although the development of regional implementation plans is the subject of this report, it is important to recognize that the need for emission-control regulations can be viewed in two different perspectives: 1) a global concern, typified by the doctrine that regardless of the ground-level pollutant concentration resulting from a given source, control devices are desirable to limit the long-term buildup of atmospheric contaminants; and 2) a regional concern, which focuses on short-term (1-hr to 1-yr) dosages at ground level. Thus, in addition to our preoccupation with regional demands, it is important to anticipate the need for parallel regulations governing uncontrolled emissions in relatively clean areas. For example, global considerations may lead to a requirement that at least 80% of all potential particulate emissions be filtered, regardless of the location and stack height of a given plant; however, the same plant might be faced with the need for a 95% efficient particulate-removal system if it is located in an air quality control region which is characterized by major source concentrations.

2.2 Land Use as a Basis for Air Resource Management Planning

An urbanizing region may be regarded as a complex system into which flow the energy, goods, services, capital, and human resources essential to the physical, economic, social, and political life of the region. Within the system, these resources are used and transformed. They are then consumed or discharged as marketable commodities, solid, liquid, and gaseous waste products, or waste energy.

From this point of view, a parcel of land that is used in a certain way may be expected to generate certain demands on the resources available to the region of which it is a part. In a developing urban-industrial region, these demands include requirements for capital, employment, water, energy, transportation facilities, housing, education and recreational facilities, certain raw materials or commodities, and public services such as law enforcement, sewage treatment, and solid-waste disposal. This array of requirements constitutes what might be termed the vector of demands associated with the parcel of land. The specific demands generated by a given parcel of land depend on the type of use to which it is put and the level of intensity to which it is developed. Measures of the level of intensity of land use are the economic activity and energy consumption associated with a parcel of land.

For example, a tract of land zoned for single family residences will generate very different demands for water, energy, goods, and services than an identical tract committed to heavy industry. There are, of course, interdependencies between the various uses to which land can be committed. For example, a parcel of land employed for industrial operations will create employment which, in turn, generates a demand for residential land in the neighborhood of the industrial area (as well as a demand for transportation facilities, etc.). The residential land, in its turn, creates a demand for certain goods and services which are supplied by committing a certain amount of the available land to commercial development. It is therefore necessary to consider land both as a generator of demands upon the air-pollution control resources available to a region and as a resource in its own right.

If the demands generated by a parcel of land depend on how it is used, it is equally true that land use will determine the type and quantity of outputs or products that are generated. Thus, a tract of commercial land will yield capital, employment opportunities, goods, services, and waste products which are different in kind and amount than the same tract would produce if it were committed to industrial, residential, or recreational use.

The proposition that the demands and output products of a parcel of land can be related more or less directly to the use to which the land is put, the intensity of development, and the associated level of economic activity is of critical importance to the regional air resource planner. This is the case because a projected pattern of land use, intensity of development, and economic activity can be used to assess the probable output of air pollutants and solid and liquid waste which can be transformed into air pollution.

Land use and the pollutants it generates, combined with a set of air quality standards, therefore constitute the elements of a demand and supply equation which the regional air resource planner must solve within the framework of the goals and objectives of the region. Since land is one of the most critical resources available to the planner, it provides an extremely powerful organizational basis for the development of regional air resource management plans. A regional air quality control plan can therefore be based upon the present and projected land-use pattern of the region, and the control program can be designed so that air-pollution emission control imposes minimum legal restrictions on the uses to which land can be put, consistent with adherence to air quality standards. The legal instrument through which this can be accomplished is the zoning ordinance.

The conception of zoning as a mechanism for air-pollution emission control is by no means original. The Chicago zoning ordinance, adopted in May 1957, was the first in the United States to apply a full scale of performance standards to industrial zoning (O'Harrow, 1954). Schulze (1960) and Frenkiel (1966) discussed the feasibility of air-pollution performance standards in zoning, and DeMarrais (1961) reported that meteorological information

for the Tulsa Metropolitan Area could be used in setting zoning performance standards and requirements. Williams *et al.* (1968) summarized the case for zoning controls and concluded that the approach was feasible provided that an atmospheric dispersion model was available and was employed properly in the formulation of land use-emission control regulations. (Several appropriate models have since been developed and validated under the sponsorship of the National Air Pollution Control Administration.)

In general, the objectives of land zoning are:

1. To secure adequate light, pure air, and safety from fire and other dangers.
2. To conserve the taxable value of land and buildings.
3. To lessen or avoid congestion in the public streets.
4. Otherwise to promote the public health, safety, comfort, morals, and welfare.

Zoning ordinances are normally enforced by a zoning administrator in a municipal department of buildings. A certificate of compliance is obtained from the zoning administrator before a building permit can be issued, and a certificate of occupancy is obtained before a building can be occupied. When an individual wishes to build a new structure or establish a new use in an existing building, he must apply to the municipal department of buildings for a permit. A zoning administrator reviews the application to determine whether the zoning regulations for the particular district permit such a use. If the zoning regulations do not permit such a use, the individual can apply for an amendment or variance to the ordinance.

Land zoning has thus traditionally been employed to establish a desired pattern of municipal and regional development. Associated with virtually all well-conceived zoning systems are various implicit or explicit nuisance-control restrictions. For example, the Chicago Zoning Ordinance recognizes three classes of manufacturing land use (M1, M2, and M3). For every standard industrial classification (SIC), the Chicago ordinance explicitly indicates the type of emission-control device which would probably, though not necessarily, qualify a given class of industry to meet the requirements to occupy land zoned in one of the three manufacturing classes. Thus, a rendering plant equipped with electrostatic precipitators will almost certainly qualify for M1 land (light industry), while the same plant equipped with baghouse filters might be relegated to M3 (heavy industry). It does not follow that the Chicago Zoning Ordinance, or others like it, constitutes an ideal legal instrument for emission control in its present form, but there is more than ample precedent for the use of land zoning as a planning tool to ensure that a desired land-use and development-intensity pattern will be established in a region--both in developed urban centers and in undeveloped areas which lie in the path of urbanization.

It therefore appears that one of the most effective ways to integrate air-pollution control with regional planning and ensure that the developmental pattern of a region will be compatible with the physical and economic resources available for air-pollution control is to use the zoning ordinance as a device to legally control the effective emission density associated with each parcel of land in the region. Just as the type and intensity of industrial, commercial, and residential activity that can be conducted on each parcel of land in a city are restricted by zoning plans designed to achieve an optimal developmental pattern for the municipality, so can the amount of sulfur oxides and particulates emitted by the occupant of a given parcel of land be controlled as part of a regional, state, county, or municipal air-pollution zoning code. The use to which land is put is thereby limited to the extent necessary to achieve the regional air quality standards. The introduction of air-pollution control into the zoning system creates, in effect, a situation in which the occupant of a certain parcel of land is the owner of certain well-defined "emission rights" which are attached permanently to the land so long as it is not rezoned.

The following discussion describes the procedure by which an array of alternative emission-density-limited zoning plans are designed. To accomplish this, the land-use patterns associated with both zoned and unincorporated land throughout the region must be established and encoded as input to a dispersion model. Fortunately, land-use and zoning data are considerably less difficult and costly to acquire than is a detailed, regional emission inventory. In the United States, the required information can usually be obtained from a number of sources. These include the zoning maps normally developed by municipal zoning authorities in all incorporated areas, U.S. Geological Survey and Soil Conservation Survey Maps, data provided by Standard Metropolitan Statistical Area (SMSA) surveys, the U.S. Department of Commerce Census of Manufacturers, and various city, state, and regional planning agencies. These sources compile and display land-use information in a compact and organized form, which tends to be considerably more manageable than conventional emission-inventory data. (A land-use or zoning inventory cannot serve as a substitute for a detailed emission inventory, since the latter is an essential prerequisite to the establishment of an operational permit system.) It is important to distinguish between "land use" and "zoning." A land-use map or survey displays an existing land-development pattern; a zoning map defines the type and limit of intensity of development that is legally permissible. The actual and the legal land development patterns may diverge significantly. This normally reflects a situation in which a portion of the land in a region has not been developed to the legal limits; however, it is not uncommon to find that both qualitative and quantitative discrepancies between land use and zoning maps arise as a result of lax enforcement practices or failure to update obsolescent zoning maps.

Once a feasible set of limiting emission densities corresponding to each land-use class defined by the zoning plan has been established, this forms the basis of a regional control plan based on land-use planning in which an air-pollution control zoning ordinance is the governing legal instrument.

2.3 Determination of Effective Emission Density Limits

Air quality standards are usually stated in terms of maximum permissible hourly, daily, and annual dosages, with allowance for violations perhaps 1-2% of the time. For example, in Illinois, the maximum permissible 24-hr average SO_2 level of 0.17 ppm can be exceeded no more than one day per year. In developing emission-control regulations according to the philosophy of the preceding section, one has the choice of studying the regional climatology and routinely clamping down on emissions to attain this standard at all times. However, it is more practical to temper the stringency of routine controls and to anticipate that for five to ten days per year, more rigid limits will be temporarily enforced. Provisions for these minor "statistical" air-pollution episodes (as well as major, infrequent ones) would be incorporated in the implementation plan.

A region-wide survey (inventory) of zoning patterns must be performed, as discussed in Section 2.2, to establish the percentage of land in each square mile zoned, in each of a specified number of zoning classes. For example, a survey may be made for: low-rise residential (RL), high-rise residential (RH), commercial (C), light industry (IL), and heavy industry (IH). In practice, zoning codes are more detailed and vary among townships and municipalities within each region; however, for emission-control regulations, they can be translated into a basic set of standard classes. For unzoned and unplanned territory, particularly large unincorporated areas, an arbitrary classification of IL will insure flexibility in future development. (A detailed discussion of zoning surveys is given in Section 3.)

Power plants, which are subjected to detailed advance planning by utilities, are considered as individual sources. The methods discussed in this section can also be used to evaluate alternative zoning plans and power-plant sites.

Emission-control regulations for routine source operation will be designated by a maximum uniform effective emission density, E_1 (mass per unit area per unit time, $\text{lb}/\text{mi}^2\text{-hr}$) for each zoning class. These will ensure that air quality standards (long-term average and short-term peak dosages) are met under all atmospheric conditions, except those designated as air-pollution episodes, for which more stringent controls are temporarily imposed.

In recent years, the meteorology of urban air pollution has been studied in sufficient theoretical and experimental detail to indicate the influences of wind speed and direction, atmospheric turbulence, and mixing-layer height, as well as local topographical effects on the potential for high pollutant levels. The air-pollution concentrations and dosages that correspond to an urban or regional distribution of discrete "point" sources and aggregated "area" sources can be estimated, for a given combination of meteorological conditions, by means of a computerized atmospheric-dispersion model. The National Air Pollution Control Administration (Martin and Tikvart, 1969) have developed a multisource model representing the crosswind and vertical diffusion of pollutants about the downwind axis of a continuous smoke plume by a Gaussian-distribution profile. Although this simulation was designed for the evaluation of long-term, "per-source" emission-control regulations, it is now being adapted by Argonne National Laboratory for the evaluation of control programs based on land use. This "Air Quality Display Model" (AQDM) requires as input seasonal or annual emission data, including the location of point and area sources, expressed in the Universal Transverse Mercator coordinate system. The air-pollution distributions associated with 480 standard combinations of wind direction, wind speed, atmospheric stability, and mixing-layer altitude are calculated at selected dose points. Seasonal or annual average pollutant concentrations are evaluated by weighting the calculated concentrations at each dose point by the observed frequency of occurrence of each standard meteorological combination. The probability of occurrence of short-term peak dosages (monthly-daily-hourly) is then estimated by applying the log-normal transformation (Larsen, 1969) to the annual or seasonal averages.

Because the AQDM is based on the manipulation of long-term average input data, it is inherently adapted to the evaluation of long-term control programs. To evaluate air-pollution episode strategies, which involve the application of emergency control procedures in response to meteorological conditions that develop on a time scale of hours or days, a transient atmospheric dispersion model is required. A transient model, which simulates three-dimensional Gaussian diffusion of pollutants, has been developed at Argonne National Laboratory under NAPCA sponsorship (Roberts *et al.*, 1969). Like the AQDM, this "integrated-puff" model requires as input a point and area-source emission inventory, and regional meteorology data (wind vector, atmospheric stability, and mixing-layer altitude). However, since the model is designed to simulate short-term transient effects, information required to estimate diurnal variations of emissions from various source types is required, and the meteorological inputs are normally in the form of hourly variations of parameters actually observed during representative, historical air-pollution episodes.

The accuracy of a dispersion model is always a valid question. The AQDM includes provision for "calibration" of the model. This is accomplished

by means of a linear regression fit of calculated values to observed air quality data. A "background" concentration can be input to improve the fit. Experience to date, obtained by applying the model in several air quality control regions, indicates that 40-80% of the observed variance is explained by the calibrated model ($R^2 = 0.4$ to 0.8).

The "integrated-puff" transient model, recently tested against approximately 10,000 receptor-hours of air quality data, correctly estimated 24-hr SO_2 averages in Chicago to better than $\pm 50\%$ of observed averages in two out of three cases (8 out of 10 cases for the more polluted regions) (Roberts *et al.*, 1969). R^2 values ranging from 0.5 for 6-hr averages to 0.7 for 24-hr averages were obtained for an uncalibrated puff model.

Both the AQDM and "integrated-puff" models can be adapted to the evaluation of land-use-based emission-control regulations. The technique is the same, whether long-term average emission data and standard sets of meteorological parameters are used to design long-range controls, or diurnal emission patterns and a selected array of historical, meteorological episodes are evaluated to develop episode-control strategies. In either case, the atmospheric dispersion model is used to calculate the concentration pattern $P_i(x,y)$ at every point x,y in the region due to a unit emission ($1 \text{ lb}/\text{mi}^2\text{-hr}$) from all areas with zoning class i (zero emissions from all other zones). For example, if 35% of the land in a particular square mile is zoned IL, an emission rate of 0.35 lb/hr would be assigned to that square mile in order to calculate the pattern $P_{IL}(x,y)$. These calculations are repeated, considering each zoning class separately, and result in a set of five patterns $P_i(x,y)$ plus a power-plant concentration profile $X_p(x,y)$ based on utility emissions (thus the use of the symbol X for pollutant concentration) assuming no particulate or sulfur controls. A representative, uniform stack height is assigned to each zoning class.

The total ground-level pollutant concentration, $X(x,y)$, is then defined by

$$X(x,y) = E_{RL}P_{RL}(x,y) + E_{RH}P_{RH}(x,y) + E_C P_C(x,y) + E_{IL}P_{IL}(x,y) + E_{IH}P_{IH}(x,y) + F_p X_p(x,y) \quad (1)$$

and related to the standards by

$$X(x,y) \leq 24\text{-hr standard, for all } (x,y). \quad (2)$$

The E_i 's (lb/hr-mi^2) represent a set of actual emission-density restrictions (the patterns were evaluated assuming a unit emission density, 1 lb/hr-mi^2), and F_p represents the fractional reduction of uncontrolled power-plant emissions. It may be desirable to consider the power plants in two or more groups, or perhaps individually, with a corresponding proliferation in F_p and $X_p(x,y)$ values. This complicates the mathematics, but

in no way affects the methodology. An air quality standard that varies within the region, perhaps reflecting demographic patterns, can be considered in Eq. 2 with negligible increase in mathematical complexity.

Clearly, there are many solutions, i.e., many combinations of E_i and F values, that will satisfy the air quality standard (Eq. 2). Five zoning

Fig. 2.1. Envelope of Feasible Solutions for a Two-dimensional Emission-density Zoning Problem

classes and one power-plant profile result in a six-dimensional volume within which the concentration $X(x,y)$ is always less than or equal to the standard. While this is difficult to visualize, the linear system, Eq. 1, and constraint Eq. 2 can be manipulated easily on a digital computer. Figure 2.1 shows the result if only two (industrial [I] and residential/commercial [RC]) instead of five zoning classes are considered. The cross-hatched area defines the allowable E_{RC} - E_I space, assuming F_p is fixed. The geometry of the hypothetical feasible solution space shown in Fig. 2.1 is established explicitly by the linear relationship between

the limiting allowable pollutant concentration at any given dose point and the corresponding emission-density limits associated with the two classes of land use. That is,

$$X(x,y) = E_{RC}P_{RC}(x,y) + E_IP_I(x,y) + F_pX_p, \quad (3)$$

where

$X(x,y)$ is the limiting concentration (dosage) specified by the air quality standards,

P_{RC} is the "normalized, overall coupling coefficient" computed by the model for residential-commercial sources at the dose point (x,y) ,

and

P_I is the "normalized, overall coupling coefficient" for industrial sources at the dose point (x,y) .

A unique pair of values for P_{RC} and P_I corresponds to each dose point. Thus, if the linear relationship defined by Eq. 3 is plotted in E_{RC} - E_I space, the limiting combinations of E_{RC} and E_I which, if applied throughout the region, would achieve the desired air quality at that particular dose point, are defined. If Eq. 3 is plotted for all dose points in the region,

a volume of $E_{RC}-E_I$ space will be defined, within which the desired air quality is achieved at all dose points. The envelope of this volume is a convex polygon having one or more vertices determined by the intersections of the linear boundaries of the feasible solutions for each dose point.

The selection of one set of (E_i, F_p) over another depends upon the evaluative criteria employed, and these are discussed briefly in Section 2.4 below. However, it is convenient just to review the application of the effective emission-density regulations, E_i , in terms of undeveloped land and in relation to the city of today. Once established, the emission limit E_i immediately tells the operator or future operator of any source on land zoned class i that his maximum allowable emission, Q_{max} , is

$$Q_{max} = \frac{A}{640} \times E_i, \quad (4)$$

where A is the number of acres associated with the plant. The regulation leaves it up to the operator to decide how compliance is to be achieved. (An existing plant may be allowed a period of several years to respond in full measure.)

The operator may consider any one or a combination of the following five options:

1. Install control devices.
2. Use cleaner fuels.
3. Reduce production.
4. Buy more land.
5. Buy emission rights from neighboring land parcels.

Item 5 is, at this point, conjectural but probably realistic. The emission-control regulations prescribe an effective emission-density set, E_i , which guarantees that regional air quality standards will be maintained. We may therefore assume that if Source A is not using its full emission quota as defined by Eq. 4, it might sell this right to Source B on an adjacent plot. There are clearly legal and political questions involved here, but a flexible system for transfer of emission rights could probably be established to meet the needs of regional planners as well as source operators.

Two important questions arise: 1) Would the purchase of sufficient land or emission rights permit an operator to avoid installing any control equipment? The answer is yes if only regional air quality standards are considered, but it is no if global emission-control regulations discussed in the introduction to this section are superimposed upon the regional emission-density limits. 2) Will not the concentration of the allowable effluent from two stacks on two parcels into one stack on a larger parcel produce higher

ground-level concentrations locally? Yes, unless the single stack is required to be higher than the original two. Thus, a traditional stack-height ordinance must be coupled with the emission-control regulations.

Operators of new or existing sources will be required to have a permit which clearly delineates the total potential emission and the method of compliance with the regulations. Existing plants in violation of these long-term emission limits must, upon applying for a permit, demonstrate a staged program of compliance. The diversity of the five options listed above requires a more extensive inspection system than, for example, uniform fuel sulfur/ash limits. By precedent, the permit/inspection system is funded by permit fees and represents a worthwhile investment by the source operators since it ensures greatest flexibility and thus the opportunity for minimizing economic disruption.

The calculational procedure described above was presented in terms of a 24-hr standard. Clearly, the same method can be applied to other averaging periods through the use of the log-normal transformation, in the case of the AQDM, or by running the transient dispersion model with one or more years of historical weather data.

Episodal emission-control regulations are evaluated in an analogous manner for two or three degrees of severity. Thus the emission-control limits in the implementation plan consist of several (E_i, F_p) sets corresponding to routine and two or more episodal-control levels. The permit system contains a record of the means by which each individual source will achieve compliance at each control level and thus provides the data for on-line emission control during episodal conditions.

2.4 Finding the Optimum Alternative

The preceding discussion has shown how, given a regional land-use pattern, an array of alternative, emission-density-limited zoning plans can be generated by means of an atmospheric dispersion model. These alternative (E_i, F_p) sets differ from one another in the magnitudes of the allowable emission densities assigned to each land-use class defined by the zoning plan, but all have in common that each set of emission-density limits will attain the established long-term or episodal regional air quality standards. Consider, for example, the simplified case illustrated in Fig. 2.1, wherein only two basic classes of land use are recognized: industrial and residential/commercial. The atmospheric dispersion model has yielded an array of limiting industrial emission-density values, each of which, in combination with a corresponding residential/commercial emission-density limit, will achieve the regional air quality standards. At one extremity of this array, all industrial emissions are curtailed and residential/commercial emissions are at the maximum possible level consistent with the air quality standards. At the other extremity, industrial emissions are at a maximum and

residential/commercial emissions are totally curtailed. Feasible solutions lie somewhere between these two extremes. From an array of alternatives, the planner must select a single set of emission density limits which will form the basis for the regional air-pollution zoning system.

The existing and projected patterns of land use throughout the region and the pattern of zoning in developing incorporated areas provide indicators of the direction in which a given region will tend to evolve. Moreover, the observed trends of demographic and economic growth (as recorded in such surveys as the U.S. Department of Commerce Census of Manufacturers and records of federal and state departments of labor) yield estimates of the developmental trends of those industrial and commercial activities within the region which tend to follow regional and national growth patterns. An extrapolation of these observed developmental trends can be used to estimate the emission densities corresponding to each land-use class which will result if "natural growth," in the absence of a regional air-pollution control program, is allowed to continue for the next 5-10 years. A computerized, trend-extrapolation model of the kind required for this purpose was developed under NAPCA sponsorship during the Chicago Air Pollution Systems Analysis Program (see Section 4). This model was employed to project sulfur oxide emissions in Chicago to the year 1980.

Present emission densities and those resulting from projected "natural" growth trends may be compared to the array of emission densities that will satisfy regional air quality standards. For the example of Fig.2.1, in which only two classes of land use are recognized, present emission densities and those corresponding to projected natural growth may be envisioned as two points (A and B) plotted in ERC-EI space. In general, these points will lie above the envelope of limiting emission densities defining the array of feasible alternative zoning plans. They indicate the direction of unimpeded growth (or decline) of emissions associated with each land-use class recognized by the zoning plan. A conventional emission inventory is necessary in order to quantify the emission density that presently corresponds to each land-use class. These data also provide a base for the development trend extrapolation required to identify the "natural-growth" point. An augmented "rapid survey" inventory (Ozolins and Smith, 1966) will normally provide a satisfactory data base for this purpose. (The rapid survey technique has undergone considerable refinement since it was originally proposed in 1966.)

An arithmetic mean emission density for a given land-use class can be obtained by dividing the total land area actually committed to this use into the corresponding total emissions derived from the inventory. Unless the analysis is confined to a highly developed urban core area, the resultant values are likely to be unrealistically low. A more rigorous evaluation would establish the percentile distribution of emission densities for each land-use class in the city or region of the present. The 95th or 99th percentile

could then be regarded as the emission density a given land-use class can attain under present conditions. These values would constitute the base for extrapolation to the point of natural growth.

The set of feasible emission-density limits lying nearest the point on this natural growth projection at the time that the regional air-pollution control plan is scheduled to be fully implemented approximates the minimum feasible perturbation of the normal course of development consistent with regional air quality standards. This plan is likely to represent the alternative that is most compatible with the perceived goals, objectives, and aspirations of the residents of the region.

The minimum perturbation solution may be formulated as a linear programming problem. If the envelope of feasible solutions is expressed by the linear relationship

$$X_{\max} = \sum_{i=1}^N E_i P_i + F_p X_p, \quad (5)$$

where

$X_{\max}$ = regional air quality standard,

E_i = emission density corresponding to zoning class i ,

P_i = coupling coefficients for zoning class i associated with those dose points which define the envelope of feasible solutions,

F_p = fractional reduction of uncontrolled power-plant emissions,

X_p = concentrations produced by power plants at dose points which define the envelope of feasible solutions,

and

N = total number of zoning classes,

then an expression of the optimum solution would be

$$\text{Min } \sum_{i=1}^N C_i A_i (E_{IG} - E_i), \quad \text{s.t. } E_i \geq E_{i \min}, \quad (6)$$

where

C_i = a weighting factor, such as land value, productivity per acre, etc., assigned to land in zoning class i ,

A_i = total land area committed to zoning class i ,

E_{iG} = emission density estimated for zoning class i at the point of "natural growth,"

and

E_{imin} = minimum possible value of E_i , based on technological limitations.

The above formulation of an "optimum solution" implies that the shortest distance between the point of natural growth and the envelope of feasible solutions defines the minimum perturbation zoning ordinance. In fact, the minimum perturbation path between the point of natural growth and the envelope may be neither a minimum distance nor a straight-line route, due to the dynamical effects associated with a diversion of regional resources away from the "natural" course of development, and into an air-pollution control program. Expression 6 is therefore only a first approximation of an optimum solution. Moreover, the point of natural growth which is extrapolated for a highly developed (and highly polluted) region may lie so far beyond the envelope of feasible emission-density limits that it is difficult to distinguish a minimum perturbation solution. In this (rather unlikely) event, alternative criteria (cost- or control-resource availability, for example) would be applied to select the optimum solution.

A minimum perturbation plan will normally correspond to a minimum-cost emission-density zoning plan. The cost of an emission-density-limited control plan must be reckoned not only in terms of the implied total cost of emission-control devices and clean fuels, but also in terms of the fact that zoning quite literally represents a long-term investment of the land resources of a city or region. A commitment of, or limitation imposed on, the use of these land resources can exert a profound economic effect on the development of the region. This clearly extends well beyond the effect on real-estate values as such, since developed land is a generator of regional economic activity as reflected in employment and the production of goods and services constituting the gross regional product.

To assess the long-range economic impact of alternative emission-density-limited zoning plans, it is not sufficient to extrapolate more intensive development of land which is presently developed or to project the growth and/or decline of existing discrete emitters. The effect of the control plan on the use and intensity of development of land that is presently at a low level of development is quite as critical as the impact on highly developed urban land, in terms of the long-range economic penalty associated with each alternative plan--a fact which has long been recognized by water-resource and transportation-system planners.

A minimum perturbation plan will correspond, more or less, directly to an optimal air-pollution control resource allocation plan. That is, it implies that the most effective possible utilization of such resources as

clean fuels, electric-power generating capacity, and land available for industrial relocation will be made. The fact that the minimum perturbation plan is likely to approximate both an optimal cost and an optimal resource allocation strategy is implicit in this approach because:

1. Operators of pollution-producing sources are provided with a very wide range of alternatives through which compliance with the emission-density-limited zoning plan may be achieved. The most economical alternative will invariably be selected by each individual plant operator. Thus, once a set of emission-density limits is established, the minimum cost penalty consistent with these will be automatically imposed on the region as a whole.

2. The minimum perturbation plan is approximated by the nearest point on the envelope of feasible solutions to the "natural-growth" point. The latter, if identified correctly, represents a state which is compatible with the physical and economic resources of the region and which will be reached if there is no need to commit more of these resources to air-pollution control than are presently committed. The nearest point on the envelope of feasible solutions to this natural growth point approximates the minimum possible diversion of the available resources required to attain acceptable air quality. Since we assume that the air quality standards must be met, any unavailable resources will have to be imported into the region. The minimum perturbation solution thus approximates the minimum possible penalty, in physical and/or economic terms, that can be paid to obtain the necessary resources--a penalty that may be manifested in many forms, ranging from the cost of additional natural-gas supply facilities to the relocation of industrial plants or transportation systems.

The minimum perturbation criterion for selecting an optimal plan does not require that a detailed source-by-source, industry-by-industry cost-effectiveness analysis, with the enormous data-acquisition problems that this approach implies, be completed before an implementation plan can be formulated. The results of a comprehensive and skillful air-pollution economics study recently published by Drexel Institute illustrate the almost insuperable practical difficulties inherent in a real-world application of the cost-effectiveness approach to air-pollution planning (Jackson et al., 1969).

2.5 The Land-use Approach as an Evaluative Technique

The preceding discussion has been directed almost entirely to the use of zoning as a legal instrument for air-pollution control. In practice, many cities and regions are almost irrevocably committed to more traditional "per-source" regulatory codes, such as process heat, process weight, and control device oriented regulations. In these cases, implementation plans generally focus on means of rendering existing regulatory codes more stringent. Where it is not politically or administratively feasible to base an

air-pollution control program on zoning, the land-use methodology can be used to evaluate the effectiveness of a set of "per-source" control regulations in terms of the regional growth potential implied by the land zoning pattern. If the atmospheric dispersion model is used to evaluate a situation in which all land in the region has been developed to the limits implied by existing zoning ordinances and the proposed "per-source" regulations are assumed to be in effect, the resultant estimates of regional air quality will indicate whether the proposed regulations are likely to be rendered obsolescent by regional growth.

2.6 Conclusions

A methodology for the design of implementation plans based on assignment of emission-density limits to each zoning class throughout an air quality control region has been proposed. Within the context of this system, all the usual control techniques, such as emission-control devices, fuel switching, and stack-height ordinances, and all the usual administrative and enforcement procedures, such as permit systems, inspections, and emission inventories, can be applied. By associating emission rights with each parcel of land in a region, the approach creates a new free-market alternative for air-pollution control. The term "air resource," which has up to the present been a rather meaningless paraphrase borrowed from water-resource planning, takes on real meaning if emission rights are attached to land use. In this situation, a regional "airshed" is as legitimate a physical, economic, and political reality as a regional watershed and can be managed in much the same way.

3. ZONING SURVEY--PROCEDURE AND APPLICATION*

(A. S. Cohen)

3.1 Discussion

A major element of a regional implementation plan for the abatement of air pollution is the control regulation. The regulations for SO_x and particulate emissions may be classified as "per-source" or "per-unit-area" types of regulations. A process-weight or process-heat regulation is classified as a per-source control. These do not directly take into account such variables as land-use intensity or absolute levels of output. These shortcomings can be eliminated by applying a regional or per-unit area-control regulation. This type of control establishes well-defined emission rights that are associated with each parcel of land in the region and are functions of intended land-use as described in Section 2.

The intended uses of land are reflected in the various zoning ordinances throughout the region. It is therefore necessary to develop a scheme for evaluating zoning before such regulations can be developed and evaluated. This section will outline the procedures for gathering and processing zoning inventories.

A zoning inventory or survey is defined as the percentage of each areal source unit throughout the region zoned for a given number of intended uses. The data-collection and analytic procedures for obtaining a zoning inventory are presented in Sections 3.2 and 3.3, respectively. The output of a zoning survey conducted for the Northeastern Illinois Metropolitan Area (NIMA) is given in Section 3.4. The NIMA region is defined as the six Illinois counties contained in the Metropolitan Chicago Air Quality Control Region as shown in Fig. 3.1.

3.2 Data Collection

3.2.1 Data Requirements

The primary data for conducting a zoning survey are zoning maps and zoning ordinances. In addition, a large map of the study region with clearly defined landmarks (roads, rivers, and county and municipality boundaries) is an essential aid.

Zoning maps can be found in many forms. Some of these are listed below in decreasing order of usefulness:

1. Composite zoning map of the entire region (unincorporated and incorporated areas).
2. Composite zoning map of county (unincorporated and incorporated areas).

*The concept of a zoning survey was formulated during the Chicago Air Pollution Systems Analysis program. The development of techniques for acquisition of zoning data and their subsequent application were conducted under Contract 31-109-38-2464 between Argonne National Laboratory and the State of Illinois.

Fig. 3.1. The Metropolitan Chicago Air Quality Control Region. ANL Neg. No. 190-1.

3. Composite zoning map of unincorporated areas of county.
4. Township zoning map of unincorporated areas.
5. Nonreproduced township zoning map of unincorporated areas.
6. Municipality zoning map.
7. Nonreproduced municipality zoning map.
8. No zoning map.

For the zoning survey conducted in the Northeastern Illinois Metropolitan Area (NIMA), each of these types of maps was used.

3.2.2 Sources of Data

Composite zoning maps are usually developed for planning purposes. Therefore, the major source of these maps would be planning commissions or boards. If a composite map is not available, then the planning group may have a complete or partial file of municipality zoning ordinances and maps. It is obviously desirable to find data sources, such as local or regional planning agencies, that have compiled much of the information sought. The only caution concerning such sources is the timeliness of the data. Often the data files are not updated.

For the NIMA study, a composite zoning map for the entire region was available from the Northeastern Illinois Planning Commission (NIPC). Since the map was made in 1964, it was not used to develop the 1970 zoning inventory. It was used, however, to compare zoning in 1964 to that in 1970. This comparison is discussed in Section 3.4.

In addition, a partial file of the municipality zoning maps was available from NIPC. Since the study area for the NIMA analysis coincided with the NIPC study area, a large study-area map was provided from this source.

A 1970 composite zoning map for McHenry County was available for use from the county's planning group. One day was required to analyze all of McHenry County using this map. Similarly, a 1970 composite map of unincorporated areas in Kane County was used.

Township zoning maps of unincorporated areas are usually available from county zoning departments. For the six counties in the NIMA study area, three of them (Cook, Du Page, and Lake) had reproduced maps. The other three (McHenry, Kane, and Will) had nonreproduced township maps. Since composite maps for McHenry and Kane Counties were available, the township maps were not needed. A survey of Will County government records was required to develop the zoning inventory for the unincorporated areas of that county.

The county zoning board also represents a possible source for municipality zoning material. Sometimes each municipality is required to file a local zoning map with the county government.

For incorporated areas, the zoning maps must be obtained directly from the municipalities or from one of the two sources given above.

3.2.3 Recommended Data-acquisition Procedure

Section 3.2.1 suggests that there is a hierarchy of data types. For example, updated composite maps are preferred to any other type of data, and composite maps of unincorporated areas are preferred to township maps of unincorporated areas, provided the latter data type is not reproduced. If township maps are reproduced in such a way that municipal zoning can be transferred onto the maps, then this is preferred to a composite map of unincorporated areas. This is because the township maps, plus the added municipality zoning, represent a composite map of the entire area, and this is preferred to a composite map of only the unincorporated areas. This hierarchy suggests that a systematic data-acquisition procedure would greatly reduce the cost and effort of the data-gathering activity.

The first step is to survey the planning groups and county zoning boards to determine the types of data available from these sources. It should be noted what areas have composite maps.* A list of the municipalities in areas for which composite maps are not available is then generated. A list of the municipalities in each county is usually available from the county office or a planning group. These lists should be checked against the municipality zoning-material files of the secondary sources, i.e., planning commissions and county zoning boards.

Those municipalities not having zoning material on file with any secondary source should be contacted to obtain copies of their zoning ordinances and maps. However, when township maps are not reproduced, it is recommended that the municipal zoning material be obtained for this area, even if copies are on file with other sources. This additional copy will allow the analyst to color-code and grid the map to simplify the analysis.

For the NIMA study, the following procedure was used to obtain municipal zoning information. A form letter (see Fig. 3.2) was sent to each municipality from which zoning material was desired. A second list of "important" municipalities was developed. Important municipalities were those known to have heavy industry. After two weeks,** all important municipalities that did not respond were telephoned. If copies of their maps were

*A map having both unincorporated and incorporated areas zoned is called a composite map unless otherwise specified.

**Ten working days.

not available and a verbal description was not practical, a personal visit was planned. All personal visits were made on the same day. During the personal visit, a street map or township map was used to outline areas of interest.

Dear Sir:

The Center for Environmental Studies at Argonne National Laboratory has recently initiated a project to develop an implementation plan for the abatement and control of air pollution. Part of this study involves the compilation of zoning maps for Cook, Du Page, Kane, Lake, McHenry, and Will Counties.

The County's Departments of Building and Zoning have already provided the zoning maps and ordinances for the unincorporated areas of this region. Since it is impractical to visit personally all the cities, towns, and villages not zoned by the County, I am asking you to send me a recent copy of your area's zoning ordinances and map(s). Your cooperation in this matter will be greatly appreciated.

Sincerely,

Fig. 3.2. Sample Form Letter

Two hundred thirty-five out of 254 municipalities were contacted during the NIMA study. Because of the availability of a composite map in McHenry County, no inquiries were sent to municipalities in the county. The remaining municipalities were all contacted regardless of the availability of zoning material from secondary sources. This was done to compile the statistics given in Tables 3.1-3.3. A response to the form letter is defined as a return letter. This letter may be the requested material, a payment requisition, or a statement that the material is not available. A response to a phone call is defined as the receipt of the material or a verbal statement that the material is not available. The response time represents the number of working days from the phone call to the response. Therefore, the total time required to receive the material is 10 days plus

the phone-call response time. Where maps are not reproduced, an attempt should be made to obtain a verbal description of the zoning over the phone. As with a personal visit, a street or township map can be used to verbally describe the important boundaries.

TABLE 3.1. Reply Times for Municipalities

Number of working days	<10	10 ≤ D ≤ 20	>20	No reply
Letter	74	38	16	61
Phone	27	0	0	14
Personal visit	5 municipalities were visited			

TABLE 3.2. Data Sources for Municipality Maps

Source Type	Municipalities	Secondary Source	Composite Map	Total Maps Used	No Data	Total Municipalities
Number supplied	155	26	19	200	54	254
Percent	60	10	8	78	22	100

TABLE 3.3. Survey Costs

Analyst cost	\$3,000
Secretarial service	350
Computer programming and related cost	650
Mailing cost	30
Travel cost	110
Purchase cost ^a	60
Total cost	\$4,200

^aOf the 235 municipalities contacted, only 13 requested remittance for the zoning material.

While waiting for municipality zoning material to arrive, the analyst can perform some of the analysis. Composite maps can be analyzed during the waiting period. In addition, township maps can be collected and municipal zoning transferred to the map from information available from secondary sources. If township maps are not reproduced, then unincorporated composite maps or non-reproduced township maps can be analyzed.

The McHenry County composite map, the Kane County unincorporated composite map, and the Will County nonreproduced township maps were analyzed during the waiting period. In addition, the Cook, Lake, and Du Page County township maps were gradually transformed to composite maps as the information arrived. The analytic procedure is designed in such a way that additional information can be used if it arrives after the analysis has been completed. Therefore, the analysis can be conducted for any section if most (70-80%) of the information is in hand. For the NIMA study, 78% of the municipalities in the six-county region had their zoning included in the analysis. The 22% not responding were considered unimportant for the study. If, however, they send in their zoning maps and ordinances the information can readily be added to the results. A more detailed description of the analytic procedure is given in Section 3.3.

3.3 The Analysis

3.3.1 Zoning Classifications

Two important decisions must be made concerning zoning classifications. First of all, the number of zoning classes to be considered must be determined. For example, eight zoning categories were used in a zoning survey of Chicago. They are: single-family residential, multifamily residential, business, commercial, limited manufacturing, general manufacturing, heavy manufacturing, and others. In contrast, the NIMA study used only four classes: limited, general, and heavy manufacturing, and other.

It is theoretically pleasing to consider as many zoning categories as possible. Practically speaking, however, each additional classification increases the number of grids to be analyzed. In addition, the time required to analyze each grid is increased. For the Chicago inventory, 247 square miles were analyzed. Conservatively estimating a 5-min average for each grid gives a total of 20.5 hr of analysis. Assuming the same average time per grid for the 4800 square miles in the NIMA region, the analysis would have taken approximately 400 hr or 2.4 man-months.

In addition to this increased time for analysis, the time for data collection and processing would increase. Since the total NIMA survey from start to finish was less than 2 man-months and the subsequent usefulness of the inventory was not substantially reduced, considerable time and money were saved by reducing the number of zoning classes.

The second task to be conducted is the development of standard definitions of zoning classes to be analyzed. The term "general manufacturing" may be used by many municipalities or counties in their zoning ordinances, but the use of the term will vary. Rather than forming strict definitions for each class, guidelines should be developed. A strict definition may not fit some of the municipality classifications. Table 3.4 represents a sample guideline for manufacturing classes. Many municipalities will have business districts that allow industrial-processing activities. For the zoning survey, these districts would most likely be called M1 districts. Similarly, a manufacturing district that allows food processing, but not the other exceptions, may still be classified as an M1 district. The assignment of zoning classes is a responsibility of the analyst. The guidelines will help make this task uniform.

TABLE 3.4. Guidelines for Industrial Classifications

M1	<u>Limited Manufacturing District</u> Must have provision for assembly, processing, fabrication, and storage plants. No raw materials shall be processed into any of the following basic products: metals of any kind, glass, plastics, textiles, leather, paper, petroleum, chemicals, or food. Also, no municipal incineration or motor-freight terminals are allowed in M1 districts.
M2	<u>General Manufacturing District</u> Has same restrictions as M1, but allows for municipal incineration and motor-freight terminals.
M3	<u>Heavy Manufacturing District</u> No restrictions.

One difficulty may arise while classifying manufacturing districts. Often a stone or sand quarry and strip mine are classified as heavy manufacturing, and no distinction is made on the zoning map. If it is desirable to create a new class for these types of sources, additional information is needed to determine what sections of the region are quarries or mines. The number of zoning classes and their definitions are a function of the intended use of the inventory. For air-pollution control, the manufacturing classes and definitions given may suffice. However, this inventory would have little use for a housing study.

3.3.2 Areal Unit Systems

To conduct a zoning survey, any type of areal unit can be used. Since the results of a zoning survey show the percentage of each areal unit zoned for a particular use, the areal units need not be uniform or even have regular shapes.

Three possible areal-unit systems are discussed below in terms of the ease of conducting the survey, the accuracy of the results, and the usefulness of the inventory. The usefulness of the zoning survey is defined in this context as its applicability to an atmospheric-dispersion model.

The first areal system uses municipal and township boundaries as units. The primary advantage of this system is that municipality and township maps would by definition represent the areas to be analyzed. This greatly simplifies the analysis. Furthermore, the number of units to consider is relatively small. For example, if these units were used rather than square miles, the number of units analyzed for the NIMA survey would have been reduced by 75%. Since fewer units are considered for the same total area, it is possible to easily increase the accuracy of the zoning inventory. This procedure is discussed in detail in Section 3.3.3.

Since the areal units are irregular in shape, analytical use of the results is prohibitively difficult. This inventory can be converted into one using regular areal units, i.e., a grid system. The zoning need only be proportionally assigned to the grids that are superimposed over each areal unit. However, this procedure assumes uniformity of zoning throughout each municipality and township. This greatly reduces the accuracy of the results. Furthermore, "hot spots" (areas zoned for heavy industry) could not be identified. For example, if Chicago were considered a single source for a zoning inventory, it would show that 7% of Chicago's 247-square-mile area is zoned for heavy industry. To make this result useful in a dispersion model, assume a square-mile grid is used. Therefore, 7% of each grid is assumed to be zoned for heavy industry. (Actually, heavy industrial zoning ranges from 0 to 89% in Chicago.)

The difficulties encountered using the municipality and township boundaries as areal units can be eliminated by using a rectangular or polar grid system. As the size of the grids decreases, the time for analysis increases. A uniform grid size is not necessary; however, as the grids get larger, the ability to locate "hot spots" decreases. Therefore, the size of the grids used must be determined based on the relative values of cost and time versus accuracy of resolution. It may be advantageous to use the grid system used in the development of an emission inventory. This would allow correlation studies between zoning and emissions.

Two disadvantages are associated with a superimposed grid areal system. First, this approach is more expensive than the political-boundary system discussed above. Since the grid system does not necessarily follow

any natural boundaries, the grid must be superimposed onto every map analyzed. (A transparent overlay is helpful when many maps analyzed have the same scale.) Considerable time is spent to align the grid properly on the many maps that need to be analyzed. Often this procedure takes more time than the analysis. The large map of the study region is a great aid for finding the coordinates of landmarks that can easily be found on the municipality or township maps.

Because grid alignment is necessary when using a regular areal system, another source of error is introduced into the analysis. In addition to the obvious errors resulting from map-scale errors and transfer errors, there are errors of aggregation. Assume township maps are not reproduced, and the inventory for the unincorporated areas must be done separately from the municipality survey. The grids that cross municipality boundaries will be analyzed more than once. Therefore, it becomes possible for a grid to be assigned more than 100% zoned for industry when the individual results are aggregated.

These errors are not very critical. With care in aligning grids, errors of less than a quarter of a mile can be obtained. With appropriate allocation schemes during aggregation, some difficulties can be corrected. More details on aggregation are provided in Section 3.3.4.

A third approach, which may not be as general as the above but has all the advantages and fewer disadvantages associated with it, uses sectional boundaries as areal units. These boundaries are marked on township and municipality maps. In addition, these are small and regular enough to avoid the problems encountered in the municipality-township-boundary approach. Such a system exists for the NIMA region. This areal system is shown in Fig. 3.3, where most of the units are square miles. In fact, in Chicago the square-mile grid system and the sectional system coincide.

Although the third approach is preferred over the other two approaches, it was not used for the NIMA survey because the square-mile grid system can be easily converted to the grid system used for an emission inventory. Furthermore, one objective of the NIMA study is to develop a general approach for generating a zoning survey and to determine the difficulties involved. This could not be done using the sectional-boundary approach.

3.3.3 A Modified Monte Carlo Procedure for Conducting a Zoning Survey

The output of a zoning survey is the percentage of land zoned in each areal unit for a given number of specified zoning classes. For a few grids, it may be practical to use a planimeter; however, for large areas, e.g., the Chicago air quality region, a quick but accurate method to analyze each grid

Fig. 3.3

Northeastern Illinois Metropolitan
Area. ANL Neg. No. 190-3.

is required. A modified Monte Carlo procedure used in many land-use surveys (see Hadfield, 1966) provides an appropriate approach for conducting a zoning survey.

To determine the percentage of a given land area zoned for manufacturing, the Monte Carlo procedure would generate a set number of random points, N , which would fall into the area being studied. If p of these points fall onto land zoned for manufacturing, then $(p/N)(100)$ is the percentage of the total area zoned for manufacturing. With a confidence level of 0.66, the actual percent area zoned for manufacturing is calculated as $(p/N)(100) \pm \sigma_p$, where

$$\sigma_p = \sqrt{pq/N} \text{ and } q = N - p.$$

For example, assume $N = 100$ and $p = 45$, then 45% of the land is zoned for industry and 55% is zoned otherwise. These figures, in all probability, are within ± 5 of the actual values,

$$4.97 = \sqrt{(45)(55)/100}.$$

The modified Monte Carlo procedure does not use a randomly generated set of points, but rather a "stratified systematic unaligned" set of points (see Fig. 3.4). As defined in Hadfield (1966),

"A stratified systematic unaligned pattern is produced as follows: a plane surface is divided into squares of equal size which constitute strata. First, a point is placed in each square in the left-hand column of squares, all points having the same Y coordinate within each square (the first Y coordinate is chosen at random) but different X coordinates, each chosen at random... . Second, points are similarly placed in the bottom row of squares, this time using a constant X coordinate but different Y 's for each square. Finally, points are placed in the remainder of the square, each point taking its X coordinate from the left-hand column in the same row and its Y from the bottom row in the same column of squares. The construction and benefits of such a pattern are further described by B. J. L. Berry." (See Berry, 1962.)

The modified approach has empirically generated smaller errors than the calculated error from the random approach. Table 3.5 compares the results of this approach and a lengthy "eyeball" approach used to obtain a zoning inventory for Chicago. Assuming the lengthy approach to be the actual value, we see that the actual "error" is indeed less than the calculated error. An example of one of these grids is given in Figs. 3.5 and 3.6.

Fig. 3.4

Stratified Systematic Un-
aligned Array of Dots

TABLE 3.5. Actual vs Calculated Errors Using
the Modified Monte Carlo Procedure

	Grid	M1	M2	M3	Other
Calculated		18	17	0	65
"Actual"	108B	18	15	0	67
Calculated error		± 3.8	± 3.8	-	± 4.8
Actual error		0	+2	0	-2
Calculated		8	28	23	31
"Actual"	115B	8	28	24	30
Calculated error		± 2.7	± 4.5	± 4.2	+1
Actual error		0	0	-1	+1
Calculated		0	17	0	83
"Actual"	24B	2	17	0	81
Calculated error		-	± 3.8	-	± 3.8
Actual error		-2	0	0	+2

CHICAGO ZONING ORDINANCE

SEC. 2, T.39N. R.13E.

MAP 4-1

RESIDENCE DISTRICTS

- R1 SINGLE-FAMILY RESIDENCE DISTRICT
- R2 SINGLE-FAMILY RESIDENCE DISTRICT
- R3 GENERAL RESIDENCE DISTRICT
- R4 GENERAL RESIDENCE DISTRICT
- R5 GENERAL RESIDENCE DISTRICT
- R6 GENERAL RESIDENCE DISTRICT
- R7 GENERAL RESIDENCE DISTRICT
- R8 GENERAL RESIDENCE DISTRICT

BUSINESS DISTRICTS

- B1-1 TO B1-5 LOCAL RETAIL DISTRICTS
- B2-1 TO B2-5 RESTRICTED RETAIL DISTRICTS
- B3-1 TO B3-5 GENERAL RETAIL DISTRICTS
- B4-1 TO B4-5 RESTRICTED SERVICE DISTRICTS
- B5-1 TO B5-5 GENERAL SERVICE DISTRICTS
- B6-6 AND B6-7 RESTRICTED CENTRAL BUSINESS DISTRICTS
- B7-5 TO B7-7 GENERAL CENTRAL BUSINESS DISTRICTS

COMMERCIAL DISTRICTS

- C1-1 TO C1-5 RESTRICTED COMMERCIAL DISTRICTS
- C2-1 TO C2-5 GENERAL COMMERCIAL DISTRICTS
- C3-1 TO C3-7 COMMERCIAL-MANUFACTURING DISTRICTS
- C4 MOTOR FREIGHT TERMINAL DISTRICT

MANUFACTURING DISTRICTS

- M1-1 TO M1-5 RESTRICTED MANUFACTURING DISTRICTS
- M2-1 TO M2-5 GENERAL MANUFACTURING DISTRICTS
- M3-1 TO M3-5 HEAVY MANUFACTURING DISTRICT

Fig. 3.5

Square Mile Zoned in Chicago.
ANL Neg. No. 190-4 Rev. 1.

RESIDENCE DISTRICTS

- R1 SINGLE-FAMILY RESIDENCE DISTRICT
- R2 SINGLE-FAMILY RESIDENCE DISTRICT
- R3 GENERAL RESIDENCE DISTRICT
- R4 GENERAL RESIDENCE DISTRICT
- R5 GENERAL RESIDENCE DISTRICT
- R6 GENERAL RESIDENCE DISTRICT
- R7 GENERAL RESIDENCE DISTRICT
- R8 GENERAL RESIDENCE DISTRICT

BUSINESS DISTRICTS

- B1-1 TO B1-5 LOCAL RETAIL DISTRICTS
- B2-1 TO B2-5 RESTRICTED RETAIL DISTRICTS
- B3-1 TO B3-5 GENERAL RETAIL DISTRICTS
- B4-1 TO B4-5 RESTRICTED SERVICE DISTRICTS
- B5-1 TO B5-5 GENERAL SERVICE DISTRICTS
- B6-6 AND B6-7 RESTRICTED CENTRAL BUSINESS DISTRICTS
- B7-5 TO B7-7 GENERAL CENTRAL BUSINESS DISTRICTS

COMMERCIAL DISTRICTS

- C1-1 TO C1-5 RESTRICTED COMMERCIAL DISTRICTS
- C2-1 TO C2-5 GENERAL COMMERCIAL DISTRICTS
- C3-1 TO C3-7 COMMERCIAL-MANUFACTURING DISTRICTS
- C4 MOTOR FREIGHT TERMINAL DISTRICT

MANUFACTURING DISTRICTS

- M1-1 TO M1-5 RESTRICTED MANUFACTURING DISTRICTS
- M2-1 TO M2-5 GENERAL MANUFACTURING DISTRICTS
- M3-1 TO M3-5 HEAVY MANUFACTURING DISTRICT

Fig. 3.6

Array of Dots Superimposed on Zoning
Map. ANL Neg. No. 190-4 Rev. 2.

Using this approach, we can analyze a single grid in less than a minute. It has the advantage of limiting the subjective judgment of the analyst which is prevalent in an eyeball approach. A point will usually fall into a zoning category or not. An arbitrary rule for borderline cases will eliminate any bias from the analyst. Furthermore, this technique can be performed by a technician, since no special training is required.

3.3.4 Data Aggregation

The output of a zoning inventory can be represented as paired vectors. The first vector identifies the source, and the second delineates the percentage of the source zoned for each use surveyed. For example, a typical output from the NIMA study is (10, 43), (1, 12, 6), where the first vector represents the x-y coordinate of the grid analyzed and the second vector shows the percent of that grid zoned for limited, general, and heavy manufacturing. These paired vectors represent a mapping (function) from grid source to zoning classes. If a composite map of the region is available, this function can be obtained without any aggregation. However, when composite maps are not available, the same source may be analyzed more than once.

This multiple analysis of the same source may occur in different ways. First, the same grid may have to be analyzed separately for unincorporated and incorporated areas. This would occur if township maps were not reproduced. Second, a superimposed grid system, by definition, does not necessarily follow natural boundaries, and therefore the grid overlay would not fit exactly all the maps analyzed. Thus, more than one map is required to completely analyze a given grid under these circumstances.

It is important to always obtain the percentage of the entire grid that is zoned in each class, even if the entire grid does not fit on the map being analyzed. The part of the grid not falling on the map is considered to be zoned "other." In this way, only a simple summation is required to obtain the complete grid analysis. Similarly, data missing during the survey can be easily added when obtained by this summation process.

As mentioned earlier, the summation process may result in some grids being zoned for more than 100% of the grid. This may result from the statistical procedure used or from grid-alignment errors. There are many ways to correct this obvious type of error. One is to proportionally reduce each zoning class in the grid to make the total equal to 100%. This was done for those grids with industrial zoning listed between 101 and 105% in the NIMA study. It was assumed that in this range the error was statistical. For grids with industrial zoning greater than 105%, the grid and its surrounding area were analyzed a second time. In this way, the excess industrial zoning area is not lost, but reallocated to the adjacent grids. It

is possible to do this reallocation automatically by proportionally allocating the excess industrial zoning to adjacent grids. This procedure is not as accurate as a reexamination of the area, but it is much quicker and can be done on a computer.

Other forms of data manipulation are possible, once the zoning inventory is complete. The original mapping of source to zoning classes can be transferred by aggregating sources or zoning classes to obtain new mappings. For the NIMA survey, the square-mile grid sources were aggregated into a nonuniform grid pattern used for an emission inventory of the region. In addition, the limited- and general-manufacturing classes were combined to obtain a light-manufacturing class. This latter aggregation is done to reduce the dimensionality of subsequent analysis if it is required.

When it is economically justified, data should be collected on small units and with large numbers of classes. This creates more flexibility of use, because the data can be converted easily upward through aggregation. Although conversion to smaller units is possible, some accuracy is usually lost.

3.4 Results

The complete 1970 zoning survey for the NIMA study area is presented below. Four types of aggregation are used and are presented in the order listed here. (See Fig. 3.7 and Table 3.6 for areal-unit designation.)

1. Areal units of square miles and zoning classes of limited, general, and heavy manufacturing (see Table 3.7).
2. Areal units of square miles and zoning class of light and heavy manufacturing (see Table 3.8).
3. Areal units of source I.D. and zoning classes of limited, general, and heavy manufacturing (see Table 3.9).
4. Areal units of source I.D. and zoning classes of light and heavy manufacturing (see Table 3.10).

The output lists the area-source identification and the percent of the source zoned in each class. (M1 = limited manufacturing, M2 = general manufacturing, M1 + M2 = light manufacturing, M3 = heavy manufacturing.) In addition, when source I.D. units are used, the size of the source in square miles is also given.

For the 1970 survey, only one square mile showed an error in aggregation. Since this error was less than 5%, the computer program used to process the raw data automatically reduced each zoning class proportionally.

Fig. 3.7. X,Y and I.D. Grid Systems. ANL Neg. No. 190-15.

TABLE 3.6. X,Y and I.D. Mapping^a

X	Y	I.D.	X	Y	I.D.	X	Y	I.D.	X	Y	I.D.	X	Y	I.D.
46	51	10	45	51	20	44	51	30	43	51	40	42	51	50
46	50	60	45	50	70	44	50	80	43	50	90	42	50	100
46	49	110	45	49	120	44	49	130	43	49	140	42	49	150
46	48	160	45	48	170	44	48	180	43	48	190	42	48	200
46	47	210	45	47	220	44	47	230	43	47	240	42	47	250
47	46	260	46	46	270	45	46	280	44	46	290	43	46	300
42	46	310	44	54	320	42	54	330	40	54	340	44	52	350
42	52	360	40	52	370	40	50	380	40	48	390	40	46	400
46	44	410	44	44	420	42	44	430	40	44	440	48	42	450
46	42	460	44	42	470	42	42	480	40	42	490	50	39	500
50	37	510	30	87	520	20	87	530	10	87	540	0	87	550
30	77	560	20	77	570	10	77	580	0	77	590	30	67	600
20	67	610	10	67	620	0	67	630	40	61	640	35	62	650
40	62	660	20	57	670	10	57	680	0	57	690	0	57	690
40	56	700	35	57	710	30	57	720	35	52	730	30	52	740
20	47	750	10	47	760	0	47	770	35	47	780	30	47	790
35	42	800	30	42	810	20	42	820	10	42	830	0	42	840
45	37	850	40	37	860	35	37	870	30	37	880	45	32	890
40	32	900	30	27	910	20	27	920	10	27	930	45	27	940
40	27	950	45	22	960	40	22	970	30	17	980	20	17	990
10	17	1000	45	17	1010	40	17	1020	40	7	1030	30	7	1040
20	7	1050	10	7	1060	50	35	1360	50	33	1370	50	31	1380
50	29	1390	50	27	1460	50	22	1550	50	12	1590	50	2	1620

^aThe X,Y coordinate is for the lower left-hand corner of the I.D. grid. Only those grids in Illinois are listed.

TABLE 3.7. X,Y Listing of 1970 Data for
Limited, General, and Heavy Manufacturing

X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL
0	40	1.	0.	0.	1.	11	45	1.	38.	0.	39.	14	52	34.	46.	0.	80.
0	42	2.	0.	0.	2.	11	47	0.	2.	0.	2.	14	53	48.	0.	0.	48.
0	69	1.	0.	0.	1.	11	48	0.	13.	1.	14.	14	54	18.	0.	0.	18.
0	90	1.	0.	0.	1.	11	49	0.	27.	0.	27.	14	57	36.	0.	0.	36.
1	42	0.	0.	4.	4.	11	52	24.	6.	0.	30.	14	58	1.	10.	30.	41.
1	46	3.	0.	0.	3.	11	53	12.	0.	0.	12.	14	59	3.	20.	67.	90.
1	63	0.	0.	1.	1.	11	57	1.	0.	6.	7.	14	60	12.	0.	4.	16.
1	91	1.	0.	0.	1.	11	58	0.	0.	6.	6.	14	61	1.	0.	0.	1.
2	44	3.	0.	0.	3.	11	59	9.	0.	21.	30.	14	63	1.	0.	0.	1.
2	46	1.	0.	0.	1.	11	60	3.	0.	0.	3.	14	73	4.	0.	0.	4.
2	50	1.	0.	0.	1.	11	61	3.	0.	0.	3.	14	74	10.	0.	0.	10.
2	51	0.	0.	5.	5.	11	62	21.	0.	17.	38.	14	76	16.	0.	0.	16.
2	54	1.	0.	0.	1.	11	63	19.	0.	0.	19.	14	82	1.	0.	0.	1.
2	58	2.	0.	0.	2.	11	64	1.	0.	0.	1.	15	6	0.	0.	2.	2.
2	64	2.	0.	0.	2.	11	65	0.	0.	2.	2.	15	16	0.	0.	40.	40.
2	65	4.	0.	0.	4.	11	66	0.	0.	13.	13.	15	17	0.	0.	100.	100.
3	51	0.	0.	8.	8.	11	67	3.	0.	15.	18.	15	18	0.	0.	61.	61.
3	61	3.	0.	0.	3.	11	70	16.	0.	0.	16.	15	19	4.	0.	36.	40.
3	65	3.	0.	0.	3.	11	71	28.	0.	18.	46.	15	20	0.	0.	2.	2.
3	81	10.	0.	6.	16.	11	72	28.	0.	28.	28.	15	21	0.	0.	4.	4.
3	82	18.	0.	6.	24.	11	73	36.	0.	0.	36.	15	22	2.	0.	5.	7.
3	83	16.	0.	0.	16.	11	74	44.	0.	0.	44.	15	24	1.	0.	0.	1.
4	61	1.	0.	0.	1.	11	75	42.	0.	0.	42.	15	25	7.	0.	0.	7.
4	69	2.	0.	0.	2.	11	76	9.	0.	0.	9.	15	30	2.	0.	0.	2.
4	70	1.	0.	0.	1.	11	83	8.	0.	0.	8.	15	31	23.	0.	0.	23.
4	71	1.	0.	0.	1.	11	91	0.	0.	6.	6.	15	32	26.	0.	0.	26.
4	79	9.	0.	0.	9.	11	92	8.	0.	10.	18.	15	33	33.	0.	0.	33.
4	80	2.	0.	0.	2.	11	93	0.	0.	4.	4.	15	36	14.	0.	0.	14.
4	81	6.	0.	0.	6.	12	41	0.	0.	1.	1.	15	37	2.	0.	0.	2.
4	91	0.	0.	7.	7.	12	42	8.	0.	29.	37.	15	38	3.	0.	0.	3.
4	92	4.	0.	0.	4.	12	43	6.	7.	4.	17.	15	42	0.	0.	62.	62.
4	93	4.	0.	0.	4.	12	44	0.	10.	8.	18.	15	43	12.	0.	24.	36.
5	50	3.	0.	0.	3.	12	45	19.	8.	17.	43.	15	44	9.	0.	0.	9.
5	56	2.	0.	0.	2.	12	48	0.	15.	8.	23.	15	45	23.	0.	0.	23.
5	69	10.	9.	0.	19.	12	49	0.	8.	31.	39.	15	49	22.	0.	0.	22.
5	70	8.	0.	8.	16.	12	50	2.	0.	0.	2.	15	50	0.	68.	0.	68.
5	71	1.	0.	0.	1.	12	52	44.	0.	0.	44.	15	51	18.	6.	0.	24.
5	78	2.	0.	0.	2.	12	53	12.	0.	0.	12.	15	52	6.	26.	0.	32.
5	79	32.	0.	0.	32.	12	57	8.	0.	46.	40.	15	56	4.	0.	0.	4.
5	80	37.	0.	0.	37.	12	58	1.	0.	9.	10.	15	57	68.	0.	0.	68.
5	81	6.	0.	0.	6.	12	59	0.	0.	32.	32.	15	58	0.	14.	0.	14.
5	84	4.	0.	0.	4.	12	60	13.	0.	8.	21.	15	59	11.	0.	0.	11.
5	91	6.	0.	3.	9.	12	61	8.	0.	0.	8.	15	60	3.	0.	0.	3.
5	92	1.	0.	1.	2.	12	62	6.	0.	0.	6.	15	72	8.	0.	0.	8.
6	40	0.	0.	12.	12.	12	63	4.	0.	0.	4.	15	73	10.	0.	0.	10.
6	42	2.	0.	0.	2.	12	66	70.	0.	5.	25.	15	88	8.	0.	0.	8.
6	48	1.	0.	0.	1.	12	67	29.	0.	16.	45.	15	89	6.	0.	1.	7.
6	50	4.	0.	0.	4.	12	68	1.	0.	19.	20.	16	10	0.	0.	23.	23.
6	59	1.	0.	0.	1.	12	71	0.	0.	14.	14.	16	11	1.	0.	10.	11.
6	59	0.	3.	0.	3.	12	73	1.	0.	0.	1.	16	16	0.	0.	20.	20.
6	78	8.	0.	0.	8.	12	74	22.	0.	0.	22.	16	17	0.	0.	86.	86.
6	79	20.	0.	0.	20.	12	75	4.	0.	0.	4.	16	18	0.	0.	82.	82.
6	91	6.	0.	0.	6.	12	77	14.	0.	0.	14.	16	19	5.	0.	23.	28.
6	92	1.	0.	0.	1.	12	78	2.	0.	0.	2.	16	20	0.	0.	65.	65.
7	40	0.	54.	54.	54.	12	79	1.	0.	0.	1.	16	21	2.	0.	24.	26.
7	62	8.	0.	0.	8.	12	80	6.	0.	0.	6.	16	22	7.	0.	3.	10.
7	63	3.	0.	2.	5.	12	81	8.	0.	2.	10.	16	24	5.	0.	0.	5.
7	65	0.	0.	2.	2.	12	83	5.	0.	0.	5.	16	25	10.	6.	0.	16.
7	66	2.	0.	4.	6.	12	85	8.	0.	0.	8.	16	27	7.	0.	0.	7.
7	68	1.	0.	0.	1.	12	86	1.	0.	0.	1.	16	30	1.	0.	4.	5.
7	75	4.	0.	0.	4.	13	92	2.	0.	0.	2.	16	31	5.	0.	56.	61.
7	92	3.	0.	0.	3.	13	3	0.	0.	9.	9.	16	32	20.	0.	40.	60.
8	40	1.	7.	63.	71.	13	4	0.	0.	47.	47.	16	33	12.	0.	23.	35.
8	41	0.	1.	5.	6.	13	5	0.	0.	30.	30.	16	34	0.	0.	6.	6.
8	44	0.	1.	2.	3.	13	6	0.	0.	37.	37.	16	35	0.	0.	2.	2.
8	45	0.	0.	19.	19.	13	16	0.	5.	2.	2.	16	36	3.	0.	4.	7.
8	48	1.	0.	0.	1.	13	22	0.	0.	5.	9.	16	42	0.	0.	40.	46.
8	50	4.	2.	0.	6.	13	42	4.	0.	72.	76.	16	43	16.	0.	10.	26.
8	52	6.	0.	0.	6.	13	44	0.	0.	42.	42.	16	45	10.	0.	0.	10.
8	62	2.	0.	0.	2.	13	49	1.	0.	0.	1.	16	52	23.	0.	0.	23.
8	66	2.	0.	0.	2.	13	57	0.	0.	7.	7.	16	72	8.	0.	0.	8.
8	77	4.	0.	0.	4.	13	58	25.	30.	1.	56.	16	79	1.	0.	0.	1.
8	80	0.	5.	2.	7.	13	59	0.	82.	8.	90.	16	81	12.	0.	0.	12.
9	41	2.	14.	23.	39.	13	60	8.	0.	0.	8.	16	88	9.	0.	0.	9.
9	42	5.	1.	15.	21.	13	61	6.	0.	0.	6.	17	10	0.	0.	15.	15.
9	43	0.	0.	22.	22.	13	62	3.	0.	0.	3.	17	11	4.	0.	1.	5.
9	44	5.	9.	14.	28.	13	63	5.	0.	0.	5.	17	18	0.	0.	9.	9.
9	45	0.	13.	5.	18.	13	66	5.	0.	0.	5.	17	19	0.	0.	18.	18.
9	48	0.	0.	2.	3.	13	67	2.	0.	0.	2.	17	20	0.	0.	100.	100.
9	49	0.	0.	11.	11.	13	69	1.	0.	4.	5.	17	21	0.	0.	97.	97.
9	50	0.	0.	28.	28.	13	72	6.	0.	0.	6.	17	22	0.	0.	72.	72.
9	52	16.	2.	10.	28.	13	73	3.	0.	0.	3.	17	23	0.	0.	36.	36.
9	53	3.	2.	0.	5.	13	74	1.	0.	47.	48.	17	25	0.	1.	1.	2.
9	60	24.	0.	0.	24.	13	75	0.	0.	14.	14.	17	30	1.	0.	18.	19.
9	61	1.	0.	0.	1.	13	81	18.	0.	3.	21.	17	31	0.	0.	70.	70.
9	63	2.	0.	0.	2.	13	82	2.	0.	0.	2.	17	32	0.	0.	59.	59.
9	91	0.	0.	7.	7.	13	83	14.	0.	0.	14.	17	33	0.	0.	62.	62.
10	39	0.	0.	8.	8.	13	89	3.	0.	0.	3.	17	34	0.	0.	41.	41.
10	41	2.	1.	0.	3.	14	3	0.	0.	20.	20.	17	35	0.	0.	3.	3.
10	42	10.	8.	18.	33.	14	4	0.	0.	80.	80.	17	36	0.	0.	3.	3.
10	43	5.	17.	10.	27.	14	7	0.	0.	8.	8.	17	43	1.	0.	1.	2.
10	44	1.	14.	6.	21.	14	11	0.	0.	40.	40.	17	46	0.	0.	1.	1.
10	45	8.	3.	14.	25.	14	13	1.	0.	0.	1.	17	47	0.	0.	4.	4.
10	47	0.	2.	17.	19.	14	16	0.	0.	29.	29.	17	52	10.	0.	0.	10.
10	48	0.	3.	10.	13.	14	17	0.	0.	7.	7.	17	57	12.	0.	0.	12.
10	49	1.	3.	0.	4.	14	18	0.	0.	7.	7.	17	80	4.	0.	0.	4.
10	50	0.	0.	2.	2.	14	19	0.	0.	27.	27.	17	87	10.	0.	0.	10.
10	52	6.	0.	0.	6.	14	20	0.	0.	8.	8.	18	7	1.	0.	0.	1.
10	53	6.	0.	0.	6.	14	21	9.	0.	4.	13.	18	13	5.	0.	0.	5.
10	57	3.	0.	4.	7.	14	22	1.	0.	10.	11.	18	14	0.	0.	16.	16.
10	58	0.	0.	4.	4.	14</											

TABLE 3.7 (Contd.)

X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL
19 7	1.	0.	4.	5.		24 26	9.	0.	0.	9.		30 39	11.	5.	0.	0.	16.
19 8	0.	0.	8.	5.		24 34	0.	0.	53.	53.		30 52	12.	0.	0.	0.	12.
19 22	0.	0.	5.	5.		24 35	0.	0.	59.	65.		30 53	8.	7.	0.	0.	15.
19 23	0.	0.	68.	68.		24 36	17.	0.	27.	44.		30 54	0.	20.	0.	0.	20.
19 24	0.	0.	68.	68.		24 37	41.	0.	0.	41.		30 55	48.	22.	3.	73.	73.
19 25	6.	0.	0.	6.		24 43	5.	0.	0.	5.		30 56	21.	0.	0.	0.	21.
19 27	0.	1.	0.	1.		24 44	38.	0.	0.	38.		30 58	4.	28.	0.	0.	32.
19 28	3.	2.	0.	5.		24 46	16.	0.	0.	16.		30 59	62.	9.	9.	80.	
19 37	0.	0.	3.	3.		24 50	10.	0.	0.	10.		30 67	2.	0.	0.	2.	
19 33	0.	0.	44.	44.		24 51	6.	0.	0.	6.		30 68	12.	0.	0.	12.	
19 43	2.	5.	0.	7.		24 52	6.	0.	0.	6.		30 69	2.	0.	0.	2.	
19 51	19.	0.	0.	19.		24 53	20.	0.	0.	20.		30 70	18.	0.	0.	18.	
19 52	1.	0.	0.	1.		24 55	6.	0.	0.	6.		30 71	6.	0.	0.	6.	
19 54	32.	0.	0.	32.		24 56	5.	0.	0.	5.		30 72	22.	0.	0.	22.	
19 55	10.	0.	0.	10.		24 57	12.	0.	0.	12.		30 78	15.	0.	0.	15.	
19 57	25.	0.	0.	25.		24 61	17.	0.	0.	17.		31 15	1.	0.	0.	1.	
19 58	4.	0.	0.	4.		24 62	60.	0.	0.	60.		31 39	4.	38.	0.	42.	
19 63	27.	0.	0.	27.		24 63	4.	0.	0.	4.		31 49	5.	0.	0.	5.	
19 77	7.	0.	0.	7.		24 64	25.	0.	0.	25.		31 51	0.	49.	16.	64.	
19 78	10.	0.	0.	10.		24 65	5.	0.	0.	5.		31 53	6.	54.	0.	60.	
20 23	0.	0.	16.	34.		24 66	5.	0.	0.	5.		31 54	5.	45.	0.	50.	
20 24	1.	2.	16.	19.		24 73	20.	0.	0.	20.		31 55	1.	71.	11.	83.	
20 28	2.	28.	0.	30.		24 85	12.	0.	0.	12.		31 58	18.	1.	0.	19.	
20 30	4.	0.	0.	4.		25 32	4.	0.	0.	4.		31 59	16.	2.	0.	18.	
20 43	18.	0.	0.	18.		25 34	0.	0.	4.	4.		31 65	2.	58.	0.	60.	
20 44	0.	0.	1.	1.		25 35	0.	0.	11.	11.		31 66	20.	25.	0.	45.	
20 48	0.	0.	8.	8.		25 36	12.	0.	71.	83.		31 67	34.	15.	0.	49.	
20 49	0.	0.	20.	20.		NEXT (M1+M2+M3) BETWEEN 100 AND 105						31 68	13.	0.	0.	13.	
20 50	3.	0.	0.	3.		25 37	100.	0.	0.	100.		31 69	0.	0.	0.	0.	
20 51	53.	0.	0.	53.		25 38	16.	0.	0.	16.		31 72	21.	0.	0.	21.	
20 52	58.	0.	0.	58.		25 45	5.	0.	0.	5.		31 71	14.	0.	0.	14.	
20 53	26.	0.	0.	26.		25 46	22.	0.	0.	22.		31 88	10.	0.	0.	10.	
20 54	46.	0.	0.	46.		25 47	40.	0.	0.	40.		31 92	23.	0.	3.	26.	
20 55	10.	0.	0.	10.		25 51	10.	0.	0.	10.		32 15	7.	0.	0.	7.	
20 57	44.	0.	0.	44.		25 52	46.	28.	0.	74.		32 22	14.	0.	0.	14.	
20 58	2.	0.	0.	2.		25 53	14.	0.	0.	14.		32 23	35.	0.	0.	35.	
20 76	1.	1.	0.	2.		25 56	28.	0.	0.	28.		32 27	0.	0.	15.	15.	
20 78	10.	0.	0.	10.		25 57	38.	0.	0.	38.		32 30	1.	0.	0.	1.	
20 81	7.	0.	0.	7.		25 62	17.	0.	0.	17.		32 31	1.	28.	0.	29.	
20 82	9.	0.	0.	9.		25 64	8.	0.	0.	8.		32 32	0.	38.	0.	38.	
21 22	0.	0.	13.	13.		25 65	63.	0.	0.	63.		32 39	0.	20.	0.	20.	
21 23	0.	0.	11.	11.		25 75	3.	0.	0.	3.		32 40	1.	53.	7.	61.	
21 24	0.	15.	36.	51.		25 78	2.	0.	0.	2.		32 41	0.	33.	0.	33.	
21 25	0.	7.	5.	14.		25 81	10.	0.	0.	10.		32 49	12.	0.	0.	12.	
21 26	0.	4.	2.	6.		25 82	2.	0.	0.	2.		32 51	0.	0.	17.	17.	
21 27	0.	0.	10.	10.		26 17	0.	0.	20.	20.		32 53	0.	0.	25.	25.	
21 28	2.	10.	37.	49.		26 18	5.	0.	32.	37.		32 54	0.	43.	0.	43.	
21 34	0.	0.	11.	11.		26 25	11.	0.	1.	12.		32 55	0.	53.	10.	63.	
21 38	0.	0.	4.	4.		26 36	17.	0.	40.	57.		32 59	4.	0.	0.	4.	
21 39	0.	0.	10.	10.		26 37	4.	0.	0.	4.		32 62	7.	2.	0.	9.	
21 50	4.	0.	0.	4.		26 38	4.	0.	0.	4.		32 63	9.	7.	0.	16.	
21 51	38.	0.	0.	38.		26 40	10.	0.	0.	10.		32 65	7.	0.	0.	7.	
21 52	56.	0.	0.	56.		26 41	5.	0.	0.	5.		32 66	62.	0.	3.	65.	
21 53	13.	0.	0.	13.		26 44	8.	0.	0.	8.		32 77	25.	7.	0.	28.	
21 54	40.	0.	0.	40.		26 51	6.	0.	0.	6.		32 78	15.	32.	24.	71.	
21 57	26.	0.	0.	26.		26 52	60.	13.	0.	73.		32 79	48.	2.	0.	50.	
21 58	71.	0.	0.	71.		26 53	16.	0.	0.	16.		32 80	47.	0.	0.	47.	
21 70	22.	0.	0.	22.		26 55	7.	0.	0.	7.		32 81	26.	0.	0.	26.	
22 24	4.	0.	12.	20.		26 62	30.	0.	0.	30.		32 82	10.	0.	0.	10.	
22 25	0.	0.	11.	11.		26 64	14.	0.	0.	14.		32 83	15.	0.	0.	15.	
22 26	0.	1.	33.	34.		27 25	1.	0.	0.	1.		32 84	6.	0.	0.	6.	
22 27	0.	0.	42.	82.		27 36	10.	0.	10.	40.		32 85	18.	5.	28.	51.	
22 28	0.	0.	55.	55.		27 37	0.	0.	20.	20.		32 86	0.	0.	11.	11.	
22 29	0.	0.	40.	40.		27 42	4.	0.	0.	4.		33 22	3.	0.	0.	3.	
22 30	2.	0.	37.	39.		27 43	4.	0.	0.	4.		33 23	6.	0.	0.	6.	
22 31	0.	0.	29.	29.		27 50	0.	0.	7.	2.		33 26	19.	0.	0.	19.	
22 32	0.	0.	30.	30.		27 81	18.	0.	7.	18.		33 27	14.	0.	0.	14.	
22 33	0.	0.	21.	21.		27 82	30.	0.	0.	30.		33 31	19.	0.	0.	19.	
22 38	0.	0.	14.	14.		27 83	12.	0.	0.	12.		33 39	0.	3.	0.	3.	
22 39	0.	0.	50.	50.		27 84	1.	0.	0.	1.		33 40	2.	11.	0.	13.	
22 49	0.	0.	2.	2.		27 85	40.	0.	0.	40.		33 41	4.	51.	5.	60.	
22 51	3.	0.	0.	3.		27 86	4.	0.	0.	4.		33 43	0.	0.	11.	11.	
22 53	10.	0.	0.	10.		27 87	4.	0.	0.	4.		33 44	0.	0.	22.	22.	
22 54	7.	0.	0.	7.		27 61	27.	0.	0.	27.		33 45	8.	0.	0.	8.	
22 57	22.	0.	0.	22.		27 62	4.	0.	0.	4.		33 46	3.	0.	0.	3.	
22 58	31.	0.	0.	31.		27 80	70.	0.	0.	20.		33 47	5.	0.	0.	5.	
22 59	9.	0.	0.	9.		27 84	1.	0.	0.	1.		33 48	3.	0.	0.	3.	
23 83	13.	0.	0.	13.		28 73	10.	0.	5.	15.		33 50	3.	0.	7.	10.	
23 70	6.	0.	0.	6.		28 74	1.	0.	0.	1.		33 51	6.	0.	45.	51.	
23 82	2.	0.	0.	2.		28 27	0.	0.	4.	4.		33 52	2.	0.	0.	2.	
23 85	20.	0.	0.	20.		28 28	0.	0.	13.	13.		33 53	0.	0.	53.	53.	
23 92	10.	0.	0.	10.		28 36	0.	0.	3.	3.		33 54	0.	13.	0.	13.	
23 23	1.	0.	0.	1.		28 37	0.	0.	94.	94.		33 55	28.	14.	3.	45.	
23 24	4.	0.	0.	4.		28 44	2.	0.	0.	2.		33 56	31.	0.	0.	31.	
23 25	10.	0.	0.	10.		28 49	10.	0.	4.	14.		33 57	3.	0.	0.	3.	
23 26	7.	1.	26.	34.		28 50	6.	0.	2.	8.		33 59	12.	0.	0.	12.	
23 27	0.	0.	1.	1.		28 51	1.	0.	8.	9.		33 62	0.	4.	0.	4.	
23 30	4.	0.	0.	4.		28 53	25.	0.	0.	25.		33 63	0.	14.	0.	14.	
23 31	0.	0.	81.	81.		28 55	2.	0.	0.	2.		33 64	5.	0.	0.	5.	
23 32	0.	0.	04.	04.		28 58	0.	75.	0.	75.		33 65	4.	0.	0.	4.	
23 33	0.	0.	27.	27.		28 59	25.	36.	0.	61.		33 68	2.	0.	0.	2.	
23 34	0.	0.	19.	19.		28 60	29.	0.	0.	29.		33 78	17.	8.	4.	24.	
23 35	5.	0.	24.	29.		28 61	12.	0.	0.	12.		33 79	25.	25.	0.	50.	
23 36	40.	0.	3.	43.		28 63	6.	0.	0.	6.		33 80	72.	10.	0.	82.	
23 37	8.	0.	0.	8.		28 75	10.	4.	0.	14.		33 81	6.	2.	10.	18.	
23 39	0.	0.	37.	37.		28 76	0.	5.	0.	5.		33 82	5.	10.	0.	15.	
23 40	1.	0.	0.	1.		28 79	7.	0.	0.	7.		33 83	0.	41.	0.	41.	
23 44	6.	0.	0.	6.		29 23	1.	0.	0.	1.		33 84	2.	1.	0.	3.	
23 46	6.	0.	0.	6.		29 30	2.	0.	0.	2.		33 85	0.	0.	7.	7.	
23 51	5.	0.	0.</														

TABLE 3.7 (Contd.)

X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL	X	Y	M1	M2	M3	TOTAL
34	61	6.	0.	0.	6.	38	42	3.	0.	70.	73.	42	61	6.	0.	0.	6.
34	62	1.	0.	0.	1.	38	43	4.	0.	0.	4.	43	19	6.	0.	0.	6.
34	63	29.	0.	0.	29.	38	44	3.	0.	53.	62.	43	20	1.	0.	0.	1.
34	64	3.	0.	0.	3.	38	45	8.	36.	45.	89.	43	22	0.	0.	5.	5.
34	65	3.	0.	0.	3.	38	47	6.	32.	0.	38.	43	27	2.	0.	0.	2.
34	77	19.	0.	0.	19.	38	49	0.	8.	0.	8.	43	28	22.	7.	0.	29.
34	78	14.	2.	0.	16.	38	52	26.	0.	0.	26.	43	29	5.	22.	0.	27.
34	79	0.	7.	0.	7.	38	56	5.	0.	0.	5.	43	31	0.	9.	0.	9.
34	87	0.	0.	30.	30.	38	57	2.	0.	0.	2.	43	32	20.	2.	0.	22.
34	90	0.	44.	0.	44.	38	58	5.	0.	0.	5.	43	33	0.	27.	42.	69.
34	91	0.	7.	0.	7.	38	59	45.	2.	0.	47.	43	34	12.	0.	0.	12.
35	11	6.	0.	0.	6.	38	60	21.	1.	0.	22.	43	35	15.	0.	18.	33.
35	23	1.	0.	0.	1.	38	64	5.	0.	0.	5.	43	36	15.	0.	0.	15.
35	25	3.	0.	0.	3.	38	65	3.	0.	0.	3.	43	40	6.	0.	0.	6.
35	27	33.	0.	0.	33.	39	19	3.	0.	0.	3.	43	41	15.	10.	0.	25.
35	36	5.	0.	0.	5.	39	22	6.	0.	0.	6.	43	42	10.	0.	0.	10.
35	38	0.	0.	5.	5.	39	23	24.	0.	0.	24.	43	43	8.	26.	0.	34.
35	41	0.	5.	0.	5.	39	33	22.	0.	18.	40.	43	44	1.	18.	0.	19.
35	42	2.	5.	50.	57.	39	34	15.	0.	2.	17.	43	45	0.	43.	30.	73.
35	43	19.	34.	33.	86.	39	35	17.	0.	0.	17.	43	46	6.	2.	4.	12.
35	44	6.	2.	79.	87.	39	36	5.	0.	0.	5.	43	47	0.	4.	60.	64.
35	45	14.	0.	11.	25.	39	37	1.	0.	0.	1.	43	48	7.	24.	0.	31.
35	48	12.	0.	0.	12.	39	39	8.	0.	0.	8.	43	50	17.	24.	0.	41.
35	49	61.	0.	0.	61.	39	41	0.	0.	55.	55.	43	52	15.	0.	15.	30.
35	53	1.	0.	0.	1.	39	42	0.	0.	70.	70.	43	53	19.	19.	15.	53.
35	54	2.	0.	0.	2.	39	44	6.	9.	0.	13.	43	54	5.	0.	0.	5.
35	60	2.	0.	0.	2.	39	45	0.	24.	52.	76.	43	55	9.	0.	0.	9.
35	64	28.	0.	0.	28.	39	46	0.	4.	37.	41.	43	56	8.	5.	0.	13.
35	65	5.	0.	0.	5.	39	47	11.	48.	2.	61.	43	57	2.	5.	0.	7.
35	68	8.	0.	0.	8.	39	48	14.	43.	0.	57.	43	59	4.	0.	0.	4.
35	69	20.	8.	0.	28.	39	49	18.	26.	0.	44.	43	60	2.	0.	0.	2.
35	70	9.	0.	0.	9.	39	50	4.	0.	0.	4.	43	61	5.	0.	0.	5.
35	73	7.	0.	0.	7.	39	51	5.	0.	0.	5.	44	16	1.	0.	0.	1.
35	81	0.	0.	25.	25.	39	52	17.	1.	0.	18.	44	21	3.	16.	0.	19.
35	82	10.	0.	6.	16.	39	55	6.	0.	0.	6.	44	22	2.	10.	31.	43.
35	83	2.	0.	0.	2.	39	56	10.	0.	0.	10.	44	23	6.	0.	8.	14.
35	84	1.	0.	0.	1.	39	57	6.	0.	0.	6.	44	24	0.	0.	5.	5.
35	85	2.	0.	0.	2.	39	60	10.	0.	0.	10.	44	25	3.	0.	0.	3.
35	90	0.	4.	0.	4.	39	61	10.	0.	0.	10.	44	26	5.	0.	0.	5.
35	91	14.	0.	0.	14.	39	62	3.	6.	0.	9.	44	27	10.	29.	0.	39.
35	92	6.	0.	0.	6.	39	63	3.	0.	0.	3.	44	28	1.	48.	0.	49.
36	10	3.	0.	0.	3.	39	64	10.	0.	0.	10.	44	29	10.	15.	0.	25.
36	11	5.	0.	0.	5.	40	21	2.	0.	0.	2.	44	30	0.	22.	0.	22.
36	12	4.	3.	0.	7.	40	22	24.	0.	0.	24.	44	31	0.	27.	0.	27.
36	22	0.	29.	0.	29.	40	23	12.	0.	0.	12.	44	32	28.	14.	0.	42.
36	23	0.	17.	0.	17.	40	29	13.	0.	0.	13.	44	33	33.	33.	0.	66.
36	26	4.	0.	0.	4.	40	33	15.	0.	5.	20.	44	34	5.	4.	0.	9.
36	27	51.	0.	0.	51.	40	34	15.	4.	44.	63.	44	35	13.	20.	0.	33.
36	35	8.	0.	3.	11.	40	35	1.	0.	3.	4.	44	36	10.	5.	0.	15.
36	36	5.	12.	2.	19.	40	41	7.	43.	0.	50.	44	37	7.	6.	0.	13.
36	37	15.	8.	0.	23.	40	42	19.	10.	0.	28.	44	38	1.	0.	0.	1.
36	38	7.	46.	3.	56.	40	43	21.	0.	0.	21.	44	39	13.	0.	0.	13.
36	39	26.	14.	0.	40.	40	44	27.	0.	0.	27.	44	40	1.	0.	0.	1.
36	40	0.	18.	0.	18.	40	45	10.	60.	5.	75.	44	41	8.	5.	0.	13.
36	41	0.	24.	0.	24.	40	46	2.	14.	22.	38.	44	43	6.	0.	0.	6.
36	42	0.	39.	26.	68.	40	47	12.	17.	0.	29.	44	44	5.	10.	0.	15.
36	43	18.	2.	0.	20.	40	48	3.	16.	3.	22.	44	45	4.	4.	84.	92.
36	44	11.	0.	17.	28.	40	49	23.	14.	0.	37.	44	46	6.	11.	25.	42.
36	45	10.	0.	0.	10.	40	50	21.	37.	0.	58.	44	47	9.	18.	36.	63.
36	48	5.	17.	0.	22.	40	51	16.	23.	0.	39.	44	48	7.	23.	0.	30.
36	49	3.	3.	0.	6.	40	52	18.	15.	0.	33.	44	49	36.	0.	0.	36.
36	53	2.	0.	0.	2.	40	53	21.	8.	0.	29.	44	50	15.	35.	0.	50.
36	54	3.	0.	0.	3.	40	54	17.	1.	0.	18.	44	51	0.	10.	46.	56.
36	57	1.	0.	0.	1.	40	55	8.	0.	0.	8.	44	52	18.	7.	10.	55.
36	58	2.	0.	0.	2.	40	56	6.	0.	0.	6.	44	53	13.	3.	0.	16.
36	64	21.	0.	0.	21.	40	57	2.	17.	0.	19.	44	54	4.	0.	0.	4.
36	65	25.	0.	0.	25.	40	60	4.	0.	0.	4.	45	12	2.	0.	0.	2.
36	66	12.	0.	0.	12.	41	70	7.	0.	0.	7.	45	17	5.	0.	0.	5.
36	70	5.	0.	0.	5.	41	23	17.	0.	0.	17.	45	19	13.	0.	0.	13.
36	71	18.	0.	0.	18.	41	29	16.	0.	0.	16.	45	22	21.	16.	47.	84.
36	72	25.	0.	0.	25.	41	30	21.	0.	0.	21.	45	23	0.	0.	73.	73.
36	81	0.	0.	12.	12.	41	32	4.	0.	4.	24.	45	24	6.	16.	4.	90.
36	82	0.	0.	27.	27.	41	33	7.	0.	18.	25.	45	25	17.	0.	11.	28.
36	83	3.	0.	20.	23.	41	34	39.	0.	30.	69.	45	26	9.	6.	0.	15.
36	84	2.	0.	57.	59.	41	35	4.	0.	12.	16.	45	27	0.	62.	0.	62.
36	85	6.	0.	45.	51.	41	40	7.	0.	0.	7.	45	28	0.	73.	0.	73.
36	86	0.	0.	7.	7.	41	41	8.	26.	0.	20.	45	29	40.	0.	0.	40.
36	88	0.	11.	0.	11.	41	42	1.	0.	0.	1.	45	30	46.	0.	0.	46.
36	89	0.	15.	0.	15.	41	43	3.	0.	0.	3.	45	31	16.	0.	0.	16.
36	90	0.	2.	0.	2.	41	44	24.	23.	0.	47.	45	32	8.	0.	0.	8.
37	20	0.	0.	2.	2.	41	45	10.	0.	60.	70.	45	33	5.	0.	0.	5.
37	26	7.	0.	0.	7.	41	46	6.	0.	61.	67.	45	34	0.	1.	36.	37.
37	27	11.	0.	0.	11.	41	47	4.	2.	0.	6.	45	35	4.	0.	0.	4.
37	25	19.	0.	11.	30.	41	48	2.	0.	0.	2.	45	36	2.	0.	0.	2.
37	36	0.	2.	4.	6.	41	49	15.	0.	0.	15.	45	37	6.	0.	0.	6.
37	37	12.	0.	0.	12.	41	50	6.	0.	0.	6.	45	39	18.	11.	0.	29.
37	38	30.	0.	0.	30.	41	51	10.	1.	0.	11.	45	40	37.	16.	0.	52.
37	41	0.	0.	48.	48.	41	52	16.	0.	0.	16.	45	41	13.	0.	0.	13.
37	42	5.	0.	70.	75.	41	53	3.	0.	0.	3.	45	42	9.	4.	0.	13.
37	43	25.	0.	0.	25.	41	54	23.	0.	0.	23.	45	43	19.	0.	0.	19.
37	44	0.	37.	22.	59.	41	59	0.	70.	0.	70.	45	44	46.	0.	0.	46.
37	45	9.	15.	0.	24.	42	20	15.	0.	0.	15.	45	45	15.	25.	0.	40.
37	52	13.	5.	0.	18.	42	21	6.	0.	0.	6.	45	46	26.	0.	0.	26.
37	53	9.	0.	0.	9.	42	23	9.	0.	0.	9.	45	47	18.	10.	6.	34.
37	54	1.	0.	0.	1.	42	29	4.	51.	0.	55.	45	48	3.	62.	9.	74.
37	57	2.	0.	0.	2.	42	30	9.	0.	0.	9.	45	49	0.	32.	0.	32.
37	58	2.	0.	0.	2.	42	37	21.	0.	0.	21.	45	50	28.	17.	0.	45.
37	59	24.	0.	0.	24.	42	33	26.	14.	51.	91.	45	51	5.	4.	5.	14.
37	60	3.	0.	0.	3.	42	34	2.	0.	18.	17.	46	32				

TABLE 3.7 (Contd.)

X	Y	M1	M2	M3	TOTAL
46	42	18.	6.	0.	24.
46	43	3.	0.	0.	3.
46	44	2.	0.	0.	2.
46	45	5.	0.	0.	5.
46	47	17.	15.	0.	32.
46	48	2.	2.	0.	4.
47	22	38.	0.	0.	38.
47	23	13.	0.	0.	13.
47	24	10.	0.	0.	10.
47	25	5.	0.	0.	5.
47	27	0.	1.	0.	1.
47	28	10.	0.	0.	10.
47	29	18.	4.	0.	22.
47	30	3.	8.	0.	11.
47	32	7.	0.	21.	28.
47	33	0.	0.	28.	28.
47	34	5.	0.	30.	35.
47	35	0.	0.	30.	30.
47	36	0.	0.	14.	14.
47	37	1.	6.	73.	80.
47	38	18.	0.	52.	70.
47	39	30.	0.	0.	30.
47	40	11.	0.	0.	11.
47	41	24.	0.	0.	24.
47	42	3.	0.	0.	3.
48	23	4.	0.	0.	4.
48	28	15.	0.	0.	15.
48	29	17.	17.	0.	34.
48	30	0.	1.	0.	1.
48	31	0.	0.	3.	3.
48	32	0.	3.	52.	55.
48	33	0.	2.	32.	34.
48	34	0.	0.	84.	84.
48	35	0.	0.	58.	58.
48	36	0.	0.	57.	57.
48	37	3.	8.	83.	94.
48	38	6.	19.	24.	49.
48	39	18.	0.	0.	18.
48	40	18.	0.	0.	18.
48	41	1.	0.	0.	1.
49	13	1.	0.	0.	1.
49	22	5.	0.	0.	5.
49	23	30.	5.	0.	35.
49	28	8.	0.	0.	8.
49	29	41.	0.	0.	41.
49	31	0.	20.	16.	36.
49	32	0.	70.	8.	78.
49	33	0.	12.	30.	42.
49	34	0.	14.	28.	42.
49	35	0.	8.	73.	81.
49	36	0.	1.	98.	100.
49	37	3.	4.	65.	72.
49	38	17.	1.	27.	45.
49	39	33.	0.	1.	34.
49	40	8.	0.	0.	8.
50	23	10.	0.	0.	10.
50	31	0.	4.	10.	14.
50	32	0.	52.	2.	54.
50	33	16.	1.	5.	22.
50	34	18.	0.	8.	26.
50	35	0.	27.	28.	55.
50	36	19.	4.	12.	35.
50	37	10.	0.	7.	17.
50	38	11.	0.	21.	32.
50	39	4.	0.	60.	64.
50	40	6.	0.	54.	60.
61	50	78.	0.	0.	78.

TABLE 3.8...X,Y Listing of 1970 Data for
Light and Heavy Manufacturing

X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL
C	40	1.	0.	1.	11	43	4.	2.	6.	14	49	16.	0.	16.	18	31	0.	7.	7.
0	42	0.	0.	2.	11	45	39.	0.	39.	14	50	92.	0.	92.	18	33	0.	54.	54.
0	69	1.	0.	1.	11	47	2.	6.	8.	14	51	37.	0.	37.	18	34	0.	51.	51.
0	90	1.	0.	1.	11	48	13.	1.	14.	14	52	80.	0.	80.	18	37	0.	27.	27.
1	42	0.	4.	4.	11	49	27.	0.	27.	14	53	48.	0.	48.	18	38	0.	6.	6.
1	46	3.	0.	3.	11	52	30.	0.	30.	14	54	18.	0.	18.	19	7	1.	4.	5.
1	63	0.	1.	1.	11	53	12.	0.	12.	14	57	36.	0.	36.	19	8	0.	8.	8.
1	91	1.	0.	1.	11	57	1.	6.	7.	14	58	11.	30.	41.	19	22	0.	5.	5.
2	44	3.	0.	3.	11	58	0.	6.	6.	14	59	23.	67.	90.	19	23	0.	68.	68.
2	46	1.	0.	1.	11	59	9.	21.	30.	14	60	12.	4.	16.	19	24	0.	68.	68.
2	50	1.	0.	1.	11	60	3.	0.	3.	14	61	1.	0.	1.	19	25	6.	0.	6.
2	51	0.	5.	5.	11	61	3.	0.	3.	14	63	1.	0.	1.	19	27	1.	0.	1.
2	54	1.	0.	1.	11	62	21.	17.	38.	14	73	4.	0.	4.	19	28	5.	0.	5.
2	58	2.	0.	2.	11	63	19.	0.	19.	14	74	10.	0.	10.	19	32	0.	3.	3.
2	64	2.	0.	2.	11	64	1.	0.	1.	14	76	16.	0.	16.	19	33	0.	44.	44.
2	65	4.	0.	4.	11	65	0.	2.	2.	14	82	1.	0.	1.	19	43	7.	0.	7.
3	51	0.	8.	8.	11	66	0.	13.	13.	15	6	0.	2.	2.	19	51	19.	0.	19.
3	61	3.	0.	3.	11	67	3.	15.	18.	15	16	0.	40.	40.	19	52	1.	0.	1.
3	65	3.	0.	3.	11	70	16.	0.	16.	15	17	0.	100.	100.	19	54	32.	0.	32.
3	81	10.	6.	16.	11	71	28.	18.	46.	15	18	0.	61.	61.	19	55	10.	0.	10.
3	82	18.	6.	24.	11	72	28.	0.	28.	15	19	4.	36.	40.	19	57	25.	0.	25.
3	83	16.	0.	16.	11	73	36.	0.	36.	15	20	0.	2.	2.	19	58	4.	0.	4.
4	61	1.	0.	1.	11	74	44.	0.	44.	15	21	4.	6.	6.	19	63	27.	0.	27.
4	69	2.	0.	2.	11	75	42.	0.	42.	15	22	2.	5.	7.	19	77	7.	0.	7.
4	70	1.	0.	1.	11	76	9.	0.	9.	15	24	1.	0.	1.	19	78	10.	0.	10.
4	71	1.	6.	7.	11	83	8.	0.	8.	15	25	7.	0.	7.	20	23	0.	34.	34.
4	79	9.	0.	9.	11	91	0.	6.	6.	15	30	2.	0.	2.	20	24	3.	16.	19.
4	80	2.	0.	2.	11	92	8.	10.	18.	15	31	23.	0.	23.	20	28	30.	0.	30.
4	81	6.	0.	6.	11	93	0.	4.	4.	15	32	26.	0.	26.	20	38	4.	0.	4.
4	91	0.	2.	2.	12	41	0.	1.	1.	15	33	33.	0.	33.	20	43	18.	0.	18.
4	92	4.	0.	4.	12	42	8.	29.	37.	15	36	14.	0.	14.	20	44	0.	1.	1.
4	93	4.	0.	4.	12	43	13.	4.	17.	15	37	2.	0.	2.	20	48	0.	8.	8.
5	50	3.	0.	3.	12	44	10.	8.	18.	15	38	3.	0.	3.	20	49	0.	20.	20.
5	56	2.	0.	2.	12	45	26.	17.	43.	15	42	0.	62.	67.	20	50	3.	0.	3.
5	69	19.	0.	19.	12	48	15.	8.	23.	15	43	12.	24.	36.	20	51	53.	0.	53.
5	70	8.	8.	16.	12	49	8.	31.	39.	15	44	9.	0.	9.	20	52	58.	0.	58.
5	71	1.	0.	1.	12	50	2.	0.	2.	15	45	23.	0.	23.	20	53	26.	0.	26.
5	78	2.	0.	2.	12	52	44.	0.	44.	15	49	22.	0.	22.	20	54	46.	0.	46.
5	79	32.	0.	32.	12	53	12.	0.	12.	15	50	68.	0.	68.	20	55	10.	0.	10.
5	80	32.	0.	32.	12	57	8.	40.	48.	15	51	24.	0.	24.	20	57	44.	0.	44.
5	81	6.	0.	6.	12	58	1.	9.	10.	15	52	32.	0.	32.	20	58	2.	0.	2.
5	84	4.	0.	4.	12	59	0.	32.	32.	15	56	4.	0.	4.	20	76	2.	0.	2.
5	91	6.	3.	9.	12	60	13.	8.	21.	15	57	68.	0.	68.	20	78	10.	0.	10.
5	92	1.	1.	2.	12	61	8.	0.	8.	15	58	14.	0.	14.	20	81	7.	0.	7.
5	93	4.	0.	4.	12	62	6.	0.	6.	15	59	11.	0.	11.	20	82	9.	0.	9.
6	40	0.	12.	12.	12	63	4.	0.	4.	15	60	3.	0.	3.	21	22	0.	13.	13.
6	42	2.	0.	2.	12	66	20.	5.	25.	15	72	8.	0.	8.	21	23	0.	11.	11.
6	48	1.	0.	1.	12	67	29.	16.	45.	15	73	10.	0.	10.	21	24	15.	26.	51.
6	50	4.	0.	4.	12	68	1.	19.	20.	15	88	8.	0.	8.	21	25	9.	5.	14.
6	59	1.	0.	1.	12	71	0.	14.	14.	15	89	6.	1.	7.	21	26	4.	2.	2.
6	69	3.	0.	3.	12	73	1.	1.	2.	16	90	23.	0.	23.	21	27	0.	10.	10.
6	78	8.	0.	8.	12	74	22.	0.	22.	16	11	1.	10.	11.	21	28	12.	37.	49.
6	79	20.	0.	20.	12	75	4.	0.	4.	16	16	0.	20.	20.	21	34	0.	11.	11.
6	91	6.	0.	6.	12	77	14.	0.	14.	16	17	0.	84.	84.	21	38	0.	4.	4.
6	92	1.	0.	1.	12	78	2.	0.	2.	16	18	0.	82.	82.	21	39	0.	10.	10.
7	40	0.	54.	54.	12	79	1.	0.	1.	16	19	5.	23.	28.	21	50	4.	0.	4.
7	62	8.	0.	8.	12	80	6.	0.	6.	16	20	0.	65.	65.	21	51	38.	0.	38.
7	63	3.	2.	5.	12	81	8.	2.	10.	16	21	2.	24.	26.	21	52	56.	0.	56.
7	65	0.	2.	2.	12	83	5.	0.	5.	16	22	7.	3.	10.	21	53	13.	0.	13.
7	66	2.	4.	6.	12	85	8.	0.	8.	16	24	5.	0.	5.	21	54	40.	0.	40.
7	68	1.	0.	1.	12	86	1.	0.	1.	16	25	16.	0.	16.	21	57	26.	0.	26.
7	75	4.	0.	4.	12	92	2.	0.	2.	16	27	7.	0.	7.	21	58	71.	0.	71.
7	92	3.	0.	3.	13	3	0.	9.	9.	16	30	1.	4.	5.	21	70	22.	0.	22.
8	40	8.	63.	71.	13	4	0.	47.	47.	16	31	5.	56.	61.	22	74	8.	12.	20.
8	41	1.	5.	6.	13	5	0.	30.	30.	16	32	20.	40.	60.	22	25	9.	2.	11.
8	44	1.	1.	2.	13	6	0.	37.	37.	16	33	12.	23.	35.	22	26	1.	33.	34.
8	45	0.	19.	19.	13	18	0.	2.	2.	16	34	0.	6.	6.	22	27	0.	0.	0.
8	48	1.	0.	1.	13	22	0.	9.	9.	16	35	0.	2.	2.	22	28	0.	55.	55.
8	50	6.	0.	6.	13	42	4.	72.	76.	16	36	3.	4.	7.	22	29	0.	40.	40.
8	52	6.	0.	6.	13	44	0.	42.	42.	16	42	6.	40.	46.	22	30	2.	37.	39.
8	62	2.	0.	2.	13	49	1.	0.	1.	16	43	16.	10.	26.	22	31	0.	29.	29.
8	66	2.	0.	2.	13	57	0.	7.	7.	16	45	10.	0.	10.	22	32	0.	20.	20.
8	77	4.	0.	4.	13	58	55.	1.	56.	16	47	21.	0.	22.	22	33	9.	21.	21.
9	40	5.	2.	7.	13	59	82.	8.	90.	16	72	8.	0.	8.	22	38	0.	14.	14.
9	41	16.	23.	39.	13	60	8.	0.	8.	16	76	1.	0.	1.	22	39	0.	50.	50.
9	42	6.	15.	21.	13	61	6.	0.	6.	16	81	12.	0.	12.	22	49	0.	2.	2.
9	43	0.	22.	22.	13	62	3.	0.	3.	16	88	9.	0.	9.	22	51	3.	0.	3.
9	44	14.	14.	28.	13	63	5.	0.	5.	17	10	0.	15.	15.	22	53	10.	0.	10.
9	45	13.	5.	18.	13	66	5.	0.	5.	17	11	4.	1.	5.	22	54	7.	0.	7.
9	48	0.	3.	3.	13	67	2.	0.	2.	17	18	0.	9.	9.	22	57	22.	0.	22.
9	49	0.	11.	11.	13	69	1.	4.	5.	17	19	0.	18.	18.	22	58	31.	0.	31.
9	50	0.	28.	28.	13	72	6.	0.	6.	17	20	0.	100.	100.	22	59	9.	0.	9.
9	52	18.	10.	28.	13	73	3.	0.	3.	17	21	0.	97.	97.	22	62	12.	0.	12.
9	53	5.	0.	5.	13	74	1.	47.	48.	17	22	0.	72.	72.	22	70	6.	0.	6.
9	60	24.	0.	24.	13	75	0.	14.	14.	17	23	0.	36.	36.	22	82	0.	2.	2.
9	61	1.	0.	1.	13	81	18.	3.	21.	17	25	1.	1.	2.	22	85	20.	0.	20.
9	63	2.	0.	2.	13	82	2.	0.	2.	17	30	1.	18.	19.	22	92	10.	0.	10.
9	91	0.	2.	2.	13	83	14.	0.	14.	17	31	0.	70.	70.	23	23	1.	0.	1.
10	39	0.	8.	8.	13	89	5.	0.	5.	17	32	0.	59.	59.	23	24	4.	4.	8.
10																			

TABLE 3.8 (Contd.)

X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL
23	87	13.	0.	13.	29	57	58.	0.	58.	34	43	34.	44.	78.	37	69	7.	0.	7.
23	88	11.	1.	12.	29	58	91.	0.	91.	34	44	0.	95.	95.	37	70	8.	0.	8.
23	89	5.	7.	12.	29	59	79.	0.	79.	34	45	2.	0.	2.	37	75	0.	43.	43.
23	91	2.	0.	2.	29	60	15.	40.	55.	34	49	7.	0.	7.	37	89	61.	0.	61.
23	92	4.	0.	4.	29	63	14.	0.	14.	34	50	22.	0.	22.	37	90	35.	0.	35.
24	23	3.	0.	3.	29	70	45.	0.	45.	34	52	4.	0.	4.	37	91	57.	0.	57.
24	25	6.	0.	6.	30	27	2.	0.	2.	34	53	0.	52.	52.	38	17	2.	0.	2.
24	26	9.	0.	9.	30	33	2.	0.	2.	34	54	25.	0.	25.	38	34	0.	7.	7.
24	34	0.	53.	53.	30	38	23.	28.	51.	34	55	38.	1.	39.	38	35	9.	95.	94.
24	35	6.	59.	65.	30	39	16.	0.	16.	34	56	7.	0.	7.	38	36	10.	17.	27.
24	36	17.	27.	44.	30	52	12.	0.	12.	34	60	3.	0.	3.	38	37	18.	0.	18.
24	37	41.	0.	41.	30	53	15.	0.	15.	34	61	6.	0.	6.	38	38	5.	0.	5.
24	43	5.	0.	5.	30	54	20.	0.	20.	34	62	1.	0.	1.	38	41	0.	55.	55.
24	44	38.	0.	38.	30	55	70.	3.	73.	34	63	29.	0.	29.	38	42	3.	70.	73.
24	46	16.	0.	16.	30	56	21.	0.	21.	34	64	3.	0.	3.	38	43	4.	0.	4.
24	50	10.	0.	10.	30	58	32.	0.	32.	34	68	3.	0.	3.	38	44	9.	53.	62.
24	51	6.	0.	6.	30	59	71.	9.	80.	34	77	19.	0.	19.	38	45	44.	45.	89.
24	52	0.	0.	0.	30	67	2.	0.	2.	34	78	16.	0.	16.	38	47	38.	0.	38.
24	53	20.	0.	20.	30	68	12.	0.	12.	34	79	7.	0.	7.	38	49	8.	0.	8.
24	55	6.	0.	6.	30	69	2.	0.	2.	34	87	0.	30.	30.	38	52	26.	0.	26.
24	56	5.	0.	5.	30	70	18.	0.	18.	34	90	44.	0.	44.	38	56	5.	0.	5.
24	57	12.	0.	12.	30	71	6.	0.	6.	34	91	7.	0.	7.	38	57	2.	0.	2.
24	61	17.	0.	17.	30	72	22.	0.	22.	35	11	6.	0.	6.	38	58	5.	0.	5.
24	62	60.	0.	60.	30	78	13.	0.	13.	35	23	1.	0.	1.	38	59	47.	0.	47.
24	63	4.	0.	4.	31	15	1.	0.	1.	35	25	3.	0.	3.	38	60	22.	0.	22.
24	64	25.	0.	25.	31	39	42.	0.	42.	35	27	33.	0.	33.	38	64	5.	0.	5.
24	65	9.	0.	9.	31	49	5.	0.	5.	35	36	5.	0.	5.	38	65	1.	0.	1.
24	66	5.	0.	5.	31	51	48.	16.	64.	35	38	0.	5.	5.	35	19	0.	0.	0.
24	71	20.	0.	20.	31	53	60.	0.	60.	35	41	5.	0.	5.	35	22	0.	0.	0.
25	05	12.	0.	12.	31	51	58.	8.	59.	35	42	7.	59.	57.	35	23	8.	0.	8.
25	32	4.	0.	4.	31	55	72.	11.	83.	35	43	53.	33.	86.	39	33	22.	13.	40.
25	34	0.	4.	4.	31	58	19.	0.	19.	35	44	8.	79.	87.	39	34	15.	2.	17.
25	35	0.	11.	11.	31	59	18.	0.	18.	35	45	14.	11.	25.	39	35	17.	0.	17.
25	36	12.	71.	83.	31	65	58.	0.	58.	35	48	12.	0.	12.	39	36	5.	0.	5.
25	37	100.	0.	100.	31	66	45.	0.	45.	35	49	61.	0.	61.	39	37	1.	0.	1.
25	38	16.	0.	16.	31	67	49.	0.	49.	35	53	1.	0.	1.	39	39	8.	0.	8.
25	45	5.	0.	5.	31	68	13.	0.	13.	35	54	2.	0.	2.	39	41	0.	55.	54.
25	46	27.	0.	27.	31	69	4.	0.	4.	35	60	2.	0.	2.	39	42	0.	70.	70.
25	47	40.	0.	40.	31	82	21.	0.	21.	35	64	28.	0.	28.	39	44	13.	0.	13.
25	51	10.	0.	10.	31	87	14.	0.	14.	35	65	5.	0.	5.	39	45	24.	52.	76.
25	52	74.	0.	74.	31	88	10.	0.	10.	35	68	8.	0.	8.	39	46	4.	17.	41.
25	53	14.	0.	14.	31	92	23.	1.	26.	35	69	28.	0.	28.	39	47	59.	2.	61.
25	56	28.	0.	28.	32	15	2.	0.	2.	35	70	8.	0.	8.	39	48	57.	0.	57.
25	57	38.	0.	38.	32	22	14.	0.	14.	35	73	7.	0.	7.	39	49	44.	0.	44.
25	62	17.	0.	17.	32	23	35.	0.	35.	35	81	0.	25.	25.	35	50	4.	0.	4.
25	64	8.	0.	8.	32	27	0.	15.	15.	35	82	10.	6.	16.	39	51	5.	0.	5.
25	65	63.	0.	63.	32	30	1.	0.	1.	35	83	2.	0.	2.	39	52	18.	0.	18.
25	75	2.	0.	2.	32	31	29.	0.	29.	35	84	1.	0.	1.	39	55	6.	0.	6.
25	78	0.	0.	0.	32	32	38.	0.	38.	35	85	2.	0.	2.	39	56	10.	0.	10.
25	81	10.	0.	10.	32	39	0.	0.	0.	35	90	4.	0.	4.	39	57	6.	0.	6.
25	82	2.	0.	2.	32	40	54.	7.	61.	35	91	14.	0.	14.	39	60	10.	0.	10.
26	17	0.	20.	20.	32	41	33.	0.	33.	35	92	6.	0.	6.	39	61	10.	0.	10.
26	18	5.	32.	37.	32	49	12.	0.	12.	36	10	3.	0.	3.	39	62	9.	0.	9.
26	25	11.	1.	12.	32	51	0.	37.	37.	36	11	5.	6.	11.	39	63	3.	0.	3.
26	36	17.	40.	57.	32	53	0.	25.	25.	36	12	7.	0.	7.	39	64	10.	0.	10.
26	37	4.	0.	4.	32	54	43.	0.	43.	36	22	29.	0.	29.	40	21	2.	0.	2.
26	38	4.	0.	4.	32	55	53.	10.	63.	36	23	17.	0.	17.	40	22	24.	0.	24.
26	40	10.	0.	10.	32	59	4.	0.	4.	36	26	4.	0.	4.	40	23	12.	0.	12.
26	41	5.	0.	5.	32	62	4.	0.	4.	36	27	51.	0.	51.	40	29	13.	0.	13.
26	44	8.	0.	8.	32	63	16.	0.	16.	36	35	8.	3.	11.	40	33	15.	5.	20.
26	51	6.	0.	6.	32	65	7.	0.	7.	36	36	17.	2.	19.	40	34	19.	44.	63.
26	52	73.	0.	73.	32	66	62.	3.	65.	36	37	23.	0.	23.	40	35	1.	3.	4.
26	53	16.	0.	16.	32	77	28.	0.	28.	36	38	53.	3.	56.	40	41	50.	0.	50.
26	55	7.	0.	7.	32	78	47.	24.	71.	36	39	40.	0.	40.	40	42	29.	0.	29.
26	62	30.	0.	30.	32	79	50.	0.	50.	36	40	18.	0.	18.	40	43	21.	0.	21.
26	63	16.	0.	16.	32	80	47.	0.	47.	36	41	24.	0.	24.	40	44	27.	0.	27.
27	25	1.	2.	3.	32	81	26.	0.	26.	36	42	39.	29.	68.	40	45	70.	5.	75.
27	30	1.	0.	1.	32	82	10.	0.	10.	36	43	20.	0.	20.	40	46	16.	2.	18.
27	36	10.	30.	40.	32	83	15.	0.	15.	36	44	11.	17.	28.	40	47	29.	0.	29.
27	37	0.	20.	20.	32	84	0.	0.	0.	36	45	10.	0.	10.	40	48	19.	3.	22.
27	42	4.	0.	4.	32	85	23.	28.	51.	36	48	22.	0.	22.	40	49	37.	0.	37.
27	43	4.	0.	4.	32	86	0.	11.	11.	36	49	6.	0.	6.	40	50	58.	0.	58.
27	50	0.	2.	2.	33	22	3.	0.	3.	36	53	2.	0.	2.	40	51	29.	0.	29.
27	51	16.	2.	18.	33	23	6.	0.	6.	36	54	3.	0.	3.	40	52	33.	0.	33.
27	52	30.	0.	30.	33	26	19.	0.	19.	36	57	1.	0.	1.	40	53	24.	0.	24.
27	53	12.	0.	12.	33	27	14.	0.	14.	36	58	2.	0.	2.	40	54	18.	0.	18.
27	55	4.	0.	4.	33	31	19.	0.	19.	36	64	21.	0.	21.	40	55	8.	0.	8.
27	56	40.	0.	40.	33	39	1.	0.	1.	36	65	12.	0.	12.	40	56	4.	0.	4.
27	57	4.	0.	4.	33	40	13.	0.	13.	36	66	0.	0.	0.	40	57	19.	0.	19.
27	60	4.	0.	4.	33	41	55.	5.	60.	36	70	5.	0.	5.	40	60	4.	0.	4.
27	61	27.	0.	27.	33	43	0.	11.	11.	36	71	18.	0.	18.	41	20	7.	0.	7.
27	62	4.	0.	4.	33	44	0.	22.	22.	36	72	25.	0.	25.	41	23	17.	0.	17.
27	80	20.	0.	20.	33	45	8.	0.	8.	36	81	0.	12.	12.	41	29	16.	0.	16.
27	84	1.	0.	1.	33	46	3.	0.	3.	36	82	0.	27.	27.	41	30	21.	0.	21.
28	23	10.	5.	15.	33	47	5.	0.	5.	36	83	3.	20.	23.	41	32	4.	0.	4.
28	24	1.	0.	1.	33	48	5.	0.	5.	36	84	2.	57.	59.	41	33	7.	18.	25.
28	27	0.	4.	4.	33	50	3.	7.	10.	36	85	6.	45.	51.	41	34	39.	30.	69.
28	28	0.	13.	13.	33	51	6.	45.	51.	36	86	0.	7.	7.	41	35	4.	1	

TABLE 3.8 (Contd.)

X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL	X	Y	M1+M2	M3	TOTAL
42	41	52.	0.	52.	44	30	22.	0.	22.	46	19	0.	30.	30.	49	13	1.	0.	1.
42	44	34.	0.	34.	44	31	27.	0.	27.	46	20	0.	5.	5.	49	22	5.	0.	5.
42	46	30.	26.	56.	44	32	42.	0.	42.	46	22	62.	12.	74.	49	23	35.	0.	35.
42	47	36.	24.	60.	44	33	66.	0.	66.	46	23	21.	51.	72.	49	28	8.	0.	8.
42	48	35.	0.	35.	44	34	9.	0.	9.	46	24	59.	18.	77.	49	29	41.	0.	41.
42	49	19.	0.	19.	44	35	33.	0.	33.	46	25	19.	0.	19.	49	31	20.	16.	36.
42	50	62.	0.	62.	44	36	15.	0.	15.	46	30	6.	0.	6.	49	32	70.	8.	78.
42	51	3.	0.	3.	44	37	13.	0.	13.	46	31	15.	0.	15.	49	33	12.	30.	42.
42	52	2.	0.	2.	44	38	1.	0.	1.	46	32	18.	2.	20.	49	34	14.	28.	42.
42	53	17.	0.	17.	44	39	13.	0.	13.	46	33	5.	27.	32.	49	35	8.	73.	81.
42	54	44.	0.	44.	44	40	1.	0.	1.	46	34	15.	25.	40.	49	36	1.	99.	100.
42	55	3.	0.	3.	44	41	13.	0.	13.	46	35	0.	65.	65.	49	37	7.	65.	72.
42	58	13.	0.	13.	44	43	6.	0.	6.	46	36	6.	33.	39.	49	38	18.	27.	45.
42	59	9.	0.	9.	44	44	15.	0.	15.	46	37	2.	13.	15.	49	39	33.	1.	34.
42	60	21.	0.	21.	44	45	8.	84.	92.	46	38	14.	17.	31.	49	40	8.	0.	8.
42	61	6.	0.	6.	44	46	17.	25.	42.	46	39	11.	0.	11.	50	23	10.	0.	10.
43	19	6.	0.	6.	44	47	27.	36.	63.	46	41	2.	0.	2.	50	31	4.	10.	14.
43	20	1.	0.	1.	44	48	30.	0.	30.	46	42	24.	0.	24.	50	32	52.	7.	54.
43	22	0.	5.	5.	44	49	36.	0.	36.	46	43	3.	0.	3.	50	33	15.	5.	20.
43	27	2.	0.	2.	44	50	50.	0.	50.	46	44	2.	0.	2.	50	34	18.	9.	26.
43	28	29.	0.	29.	44	51	10.	46.	56.	46	45	5.	0.	5.	50	35	27.	28.	55.
43	29	27.	0.	27.	44	52	25.	30.	55.	46	47	32.	0.	32.	50	36	23.	12.	35.
43	31	9.	0.	9.	44	53	16.	0.	16.	46	48	4.	0.	4.	50	37	10.	6.	16.
43	32	22.	0.	22.	44	54	4.	0.	4.	47	22	38.	0.	38.	50	38	11.	21.	32.
43	33	27.	42.	69.	45	12	2.	0.	2.	47	23	13.	0.	13.	50	39	4.	68.	72.
43	34	12.	0.	12.	45	17	5.	0.	5.	47	24	10.	0.	10.	50	40	6.	54.	60.
43	35	15.	18.	33.	45	19	13.	0.	13.	47	25	5.	0.	5.	61	58	28.	0.	28.
43	36	15.	0.	15.	45	22	37.	47.	84.	47	27	1.	0.	1.					
43	40	6.	0.	6.	45	23	0.	73.	73.	47	28	10.	0.	10.					
43	41	25.	0.	25.	45	24	22.	77.	99.	47	29	22.	0.	22.					
43	42	10.	0.	10.	45	25	17.	11.	28.	47	30	11.	0.	11.					
43	43	34.	0.	34.	45	26	15.	0.	15.	47	32	7.	21.	28.					
43	44	19.	0.	19.	45	27	62.	0.	62.	47	33	0.	29.	28.					
43	45	43.	30.	73.	45	28	73.	0.	73.	47	34	5.	30.	35.					
43	46	8.	4.	12.	45	29	69.	0.	69.	47	35	0.	30.	30.					
43	47	4.	60.	64.	45	30	46.	0.	46.	47	36	0.	14.	14.					
43	48	31.	0.	31.	45	31	16.	0.	16.	47	37	7.	73.	80.					
43	50	41.	0.	41.	45	32	8.	0.	8.	47	38	18.	52.	70.					
43	52	15.	15.	30.	45	33	5.	0.	5.	47	39	30.	0.	30.					
43	53	38.	15.	53.	45	34	1.	36.	37.	47	40	11.	0.	11.					
43	54	5.	0.	5.	45	35	4.	0.	4.	47	41	24.	0.	24.					
43	55	9.	0.	9.	45	36	2.	0.	2.	47	42	3.	0.	3.					
43	56	13.	0.	13.	45	37	6.	0.	6.	48	23	4.	0.	4.					
43	58	7.	0.	7.	45	39	29.	0.	29.	48	28	15.	0.	15.					
43	59	4.	0.	4.	45	40	53.	0.	53.	48	29	49.	0.	49.					
43	60	2.	0.	2.	45	41	13.	0.	13.	48	30	7.	0.	7.					
43	61	5.	0.	5.	45	42	13.	0.	13.	48	31	0.	3.	3.					
44	16	1.	0.	1.	45	43	19.	0.	19.	48	32	3.	52.	55.					
44	21	19.	0.	19.	45	44	46.	0.	46.	48	33	2.	32.	34.					
44	22	12.	31.	43.	45	45	40.	0.	40.	48	34	0.	84.	84.					
44	23	6.	8.	14.	45	46	26.	0.	26.	48	35	0.	59.	59.					
44	24	0.	5.	5.	45	47	28.	6.	34.	48	36	0.	57.	57.					
44	25	3.	0.	3.	45	48	65.	9.	74.	48	37	11.	83.	94.					
44	26	5.	0.	5.	45	49	32.	0.	32.	48	38	24.	24.	48.					
44	27	39.	0.	39.	45	50	45.	0.	45.	48	39	18.	0.	18.					
44	28	49.	0.	49.	45	51	9.	6.	14.	49	40	18.	0.	18.					
44	29	25.	0.	25.	46	18	1.	15.	16.	49	41	1.	0.	1.					

TABLE 3.9. I.D. Listing of 1970 Data for Limited, General, and Heavy Manufacturing

ID	M1	M2	M3	AREA	ID	M1	M2	M3	AREA	ID	M1	M2	M3	AREA
10	0.0	0.0	0.0	1.00	580	1.10	0.0	0.05	100.00	1150	0.0	0.0	0.0	1.00
20	5.00	4.00	5.00	1.00	590	1.81	0.0	0.12	100.00	1160	0.0	0.0	0.0	1.00
30	0.0	10.00	46.00	1.00	600	2.27	0.23	0.0	100.00	1170	0.0	0.0	0.0	1.00
40	0.0	0.0	0.0	1.00	610	1.37	0.10	0.0	100.00	1180	0.0	0.0	0.0	1.00
50	3.00	0.0	0.0	1.00	620	3.61	0.0	1.47	100.00	1190	0.0	0.0	0.0	1.00
60	0.0	0.0	0.0	1.00	630	0.29	0.12	0.14	100.00	1200	0.0	0.0	0.0	1.00
70	28.00	17.00	0.0	1.00	640	0.44	0.0	0.0	25.00	1210	0.0	0.0	0.0	1.00
80	15.00	35.00	0.0	1.00	650	4.88	0.24	0.0	25.00	1220	0.0	0.0	0.0	1.00
90	17.00	24.00	0.0	1.00	660	6.16	4.37	0.12	25.00	1230	0.0	0.0	0.0	1.00
100	21.00	41.00	0.0	1.00	670	7.62	2.68	0.40	100.00	1240	0.0	0.0	0.0	1.00
110	0.0	0.0	0.0	1.00	680	4.65	1.56	2.94	100.00	1250	0.0	0.0	0.0	1.00
120	0.0	32.00	0.0	1.00	690	0.60	0.0	0.09	100.00	1260	0.0	0.0	0.0	1.00
130	36.00	0.0	0.0	1.00	700	3.04	4.32	0.0	25.00	1270	0.0	0.0	0.0	1.00
140	0.0	0.0	0.0	1.00	710	5.46	0.12	0.0	25.00	1280	0.0	0.0	0.0	1.00
150	19.00	0.0	0.0	1.00	720	5.12	1.60	0.36	25.00	1290	0.0	0.0	0.0	1.00
160	2.00	2.00	0.0	1.00	730	3.80	0.60	0.0	25.00	1300	0.0	0.0	0.0	1.00
170	3.00	62.00	9.00	1.00	740	7.12	15.80	6.32	25.00	1310	0.0	0.0	0.0	1.00
180	7.00	23.00	0.0	1.00	750	9.20	0.55	0.48	100.00	1320	0.0	0.0	0.0	1.00
190	7.00	24.00	0.0	1.00	760	3.91	3.40	0.79	100.00	1330	0.0	0.0	0.0	1.00
200	18.00	17.00	0.0	1.00	770	0.42	0.06	0.65	100.00	1340	0.0	0.0	0.0	1.00
210	17.00	15.00	0.0	1.00	780	5.56	7.08	0.08	25.00	1350	0.0	0.0	0.0	1.00
220	18.00	10.00	6.00	1.00	790	2.28	2.24	4.20	25.00	1360	4.75	7.75	10.00	4.00
230	9.00	18.00	36.00	1.00	800	5.64	8.52	25.52	25.00	1370	8.00	0.25	3.25	4.00
240	0.0	4.00	60.00	1.00	810	2.80	1.16	7.08	25.00	1380	0.0	14.00	3.00	4.00
250	8.00	28.00	24.00	1.00	820	4.33	0.0	3.13	100.00	1390	0.0	0.0	0.0	4.00
260	0.0	0.0	0.0	1.00	830	2.06	1.17	7.61	100.00	1400	0.0	0.0	0.0	4.00
270	0.0	0.0	0.0	1.00	840	0.25	0.51	2.39	100.00	1410	0.0	0.0	0.0	4.00
280	26.00	0.0	0.0	1.00	850	11.52	2.90	14.20	25.00	1420	0.0	0.0	0.0	4.00
290	6.00	11.00	25.00	1.00	860	4.68	3.76	0.0	25.00	1430	0.0	0.0	0.0	4.00
300	6.00	2.00	4.00	1.00	870	4.88	4.60	6.64	25.00	1440	0.0	0.0	0.0	4.00
310	13.00	17.00	26.00	1.00	880	1.72	8.56	1.60	25.00	1450	0.0	0.0	0.0	4.00
320	1.00	0.0	0.0	4.00	890	3.00	4.44	33.28	25.00	1460	0.0	0.0	0.0	4.00
330	9.00	6.25	0.0	4.00	900	11.72	4.92	9.52	25.00	1470	0.0	0.0	0.0	4.00
340	12.00	0.25	0.0	4.00	910	2.76	0.80	1.64	100.00	1480	0.0	0.0	0.0	4.00
350	7.75	2.50	7.50	4.00	920	1.24	0.38	9.01	100.00	1490	0.0	0.0	0.0	4.00
360	11.25	6.75	7.50	4.00	930	1.68	0.20	5.77	100.00	1500	0.0	0.0	0.0	4.00
370	14.50	5.75	0.0	4.00	940	10.56	8.28	0.76	25.00	1510	0.0	0.0	0.0	4.00
380	13.25	15.25	0.0	4.00	950	4.56	9.20	0.0	25.00	1520	0.0	0.0	0.0	4.00
390	10.75	7.50	0.75	4.00	960	10.04	4.44	11.56	25.00	1530	0.0	0.0	0.0	36.00
400	6.00	8.25	20.75	4.00	970	3.12	0.40	1.96	25.00	1540	0.0	0.0	0.0	100.00
410	1.75	0.0	0.0	4.00	980	1.43	0.46	0.02	100.00	1550	0.0	0.0	0.0	25.00
420	17.50	9.75	21.00	4.00	990	0.74	0.65	2.58	100.00	1560	0.0	0.0	0.0	25.00
430	0.75	23.25	7.50	4.00	1000	0.65	0.31	12.04	100.00	1570	0.0	0.0	0.0	25.00
440	17.75	20.75	16.25	4.00	1010	0.76	0.0	2.00	25.00	1580	0.0	0.0	0.0	25.00
450	0.0	0.0	0.0	4.00	1020	1.64	0.64	0.04	25.00	1590	0.0	0.0	0.0	100.00
460	6.00	1.50	0.0	4.00	1030	0.04	0.0	0.0	100.00	1600	0.0	0.0	0.0	100.00
470	8.50	1.00	0.0	4.00	1040	0.21	0.03	0.06	100.00	1610	0.0	0.0	0.0	100.00
480	4.50	6.50	0.0	4.00	1050	0.0	0.0	0.0	100.00	1620	0.0	0.0	0.0	100.00
490	10.75	2.50	0.0	4.00	1060	0.13	0.0	1.85	100.00	1630	0.0	0.0	0.0	100.00
500	2.50	0.0	30.50	4.00	1070	0.0	0.0	0.0	1.00	1640	0.0	0.0	0.0	100.00
510	5.25	0.0	6.75	4.00	1080	0.0	0.0	0.0	1.00	1650	0.0	0.0	0.0	25.00
520	1.11	1.92	0.33	100.00	1090	0.0	0.0	0.0	1.00	1660	0.0	0.0	0.0	25.00
530	0.22	0.23	0.08	100.00	1100	0.0	0.0	0.0	1.00	1670	0.0	0.0	0.0	4.00
540	0.46	0.0	0.21	100.00	1110	0.0	0.0	0.0	1.00	1680	0.0	0.0	0.0	1.00
550	0.31	0.0	0.08	100.00	1120	0.0	0.0	0.0	1.00	1690	0.0	0.0	0.0	1.00
560	4.27	1.48	3.37	100.00	1130	0.0	0.0	0.0	1.00					
570	1.13	0.0	0.0	100.00	1140	0.0	0.0	0.0	1.00					

TABLE 3.10. I.D. Listing of 1970 Data for
Light and Heavy Manufacturing

ID	M1+M2	M3	AREA	ID	M1+M2	M3	AREA	ID	M1+M2	M3	AREA
10	0.0	0.0	1.00	580	1.10	0.05	100.00	1150	0.0	0.0	1.00
20	9.00	5.00	1.00	590	1.81	0.12	100.00	1160	0.0	0.0	1.00
30	10.00	46.00	1.00	600	2.50	0.0	100.00	1170	0.0	0.0	1.00
40	0.0	0.0	1.00	610	1.47	0.0	100.00	1180	0.0	0.0	1.00
50	3.00	0.0	1.00	620	3.61	1.47	100.00	1190	0.0	0.0	1.00
60	0.0	0.0	1.00	630	0.41	0.14	100.00	1200	0.0	0.0	1.00
70	45.00	0.0	1.00	640	0.44	0.0	25.00	1210	0.0	0.0	1.00
80	50.00	0.0	1.00	650	5.12	0.0	25.00	1220	0.0	0.0	1.00
90	41.00	0.0	1.00	660	10.48	0.12	25.00	1230	0.0	0.0	1.00
100	62.00	0.0	1.00	670	10.30	0.40	100.00	1240	0.0	0.0	1.00
110	0.0	0.0	1.00	680	6.21	2.94	100.00	1250	0.0	0.0	1.00
120	32.00	0.0	1.00	690	0.60	0.09	100.00	1260	0.0	0.0	1.00
130	36.00	0.0	1.00	700	7.36	0.0	25.00	1270	0.0	0.0	1.00
140	0.0	0.0	1.00	710	5.60	0.0	25.00	1280	0.0	0.0	1.00
150	19.00	0.0	1.00	720	6.72	0.36	25.00	1290	0.0	0.0	1.00
160	4.00	0.0	1.00	730	4.40	0.0	25.00	1300	0.0	0.0	1.00
170	65.00	9.00	1.00	740	22.92	6.32	25.00	1310	0.0	0.0	1.00
180	30.00	0.0	1.00	750	9.75	0.48	100.00	1320	0.0	0.0	1.00
190	31.00	0.0	1.00	760	7.31	0.79	100.00	1330	0.0	0.0	1.00
200	35.00	0.0	1.00	770	0.48	0.65	100.00	1340	0.0	0.0	1.00
210	32.00	0.0	1.00	780	12.64	0.08	25.00	1350	0.0	0.0	1.00
220	28.00	6.00	1.00	790	4.52	4.20	25.00	1360	12.50	10.00	4.00
230	27.00	36.00	1.00	800	14.16	25.52	25.00	1370	8.25	3.25	4.00
240	4.00	60.00	1.00	810	3.96	7.08	25.00	1380	14.00	3.00	4.00
250	36.00	24.00	1.00	820	4.33	3.13	100.00	1390	0.0	0.0	4.00
260	0.0	0.0	1.00	830	3.23	7.61	100.00	1400	0.0	0.0	4.00
270	0.0	0.0	1.00	840	0.76	2.39	100.00	1410	0.0	0.0	4.00
280	26.00	0.0	1.00	850	14.32	14.20	25.00	1420	0.0	0.0	4.00
290	17.00	25.00	1.00	860	8.44	0.0	25.00	1430	0.0	0.0	4.00
300	8.00	4.00	1.00	870	9.48	6.64	25.00	1440	0.0	0.0	4.00
310	30.00	26.00	1.00	880	10.28	1.60	25.00	1450	0.0	0.0	4.00
320	1.00	0.0	4.00	890	7.44	33.28	25.00	1460	0.0	0.0	4.00
330	15.25	0.0	4.00	900	16.64	9.52	25.00	1470	0.0	0.0	4.00
340	12.25	0.0	4.00	910	3.56	1.64	100.00	1480	0.0	0.0	4.00
350	10.25	7.50	4.00	920	1.62	9.01	100.00	1490	0.0	0.0	4.00
360	18.00	7.50	4.00	930	1.88	5.77	100.00	1500	0.0	0.0	4.00
370	20.25	0.0	4.00	940	18.84	0.76	25.00	1510	0.0	0.0	4.00
380	28.50	0.0	4.00	950	13.76	0.0	25.00	1520	0.0	0.0	4.00
390	18.25	0.75	4.00	960	14.48	11.56	25.00	1530	0.0	0.0	36.00
400	14.25	20.75	4.00	970	3.52	1.96	25.00	1540	0.0	0.0	100.00
410	1.75	0.0	4.00	980	1.85	0.02	100.00	1550	0.40	0.0	25.00
420	27.25	21.00	4.00	990	1.39	2.58	100.00	1560	0.0	0.0	25.00
430	24.00	7.50	4.00	1000	0.96	12.04	100.00	1570	0.0	0.0	25.00
440	38.50	16.25	4.00	1010	0.76	2.00	25.00	1580	0.0	0.0	25.00
450	0.0	0.0	4.00	1020	2.28	0.04	25.00	1590	0.0	0.0	100.00
460	7.50	0.0	4.00	1030	0.04	0.0	100.00	1600	0.0	0.0	100.00
470	9.50	0.0	4.00	1040	0.24	0.06	100.00	1610	0.0	0.0	100.00
480	11.00	0.0	4.00	1050	0.0	0.0	100.00	1620	0.0	0.0	100.00
490	13.25	0.0	4.00	1060	0.13	1.85	100.00	1630	0.0	0.0	100.00
500	2.50	30.50	4.00	1070	0.0	0.0	1.00	1640	0.0	0.0	100.00
510	5.25	6.75	4.00	1080	0.0	0.0	1.00	1650	0.0	0.0	25.00
520	3.03	0.33	100.00	1090	0.0	0.0	1.00	1660	0.0	0.0	25.00
530	0.45	0.08	100.00	1100	0.0	0.0	1.00	1670	0.0	0.0	4.00
540	0.46	0.21	100.00	1110	0.0	0.0	1.00	1680	0.0	0.0	1.00
550	0.31	0.08	100.00	1120	0.0	0.0	1.00	1690	0.0	0.0	1.00
560	5.75	3.37	100.00	1130	0.0	0.0	1.00				
570	1.13	0.0	100.00	1140	0.0	0.0	1.00				

The final listing (Table 3.11) is the 1964 zoning survey. This survey was incomplete. Two major areas not included in the survey were Will County and Chicago. In addition, only two zoning classes were considered. They are M1 = light manufacturing and M2 = heavy manufacturing. The M3 class represents the portion of a source left unzoned because of the incomplete nature of the survey.

A meaningful comparison between the 1970 and the 1964 surveys for the area outside Will County and Chicago could not be made on a square-mile basis because of grid-alignment errors. Therefore, only a source I.D. comparison (including 40 sources) was performed. Of the 40 sources, eight, six, and seven had changes of greater than 2% i.e., $|M(1970) - M(1964)| > 2\%$, for light, heavy, and total manufacturing, respectively. This represents a maximum of 20% of the sources showing any change in industrial zoning. It was assumed that a change of greater than 2% represented an actual change and not a statistical variation.

In addition, only 5% of the sources showed changes of greater than 10% in industrial zoning, and none showed changes greater than 15%. Considering the fact that the industrial zoning in Chicago has not changed greatly over the six-year period, the total percent changes in zoning would be even smaller.

One important assumption used while making the comparison should be mentioned. If the incomplete portion of any source in the 1964 survey could account for the difference in the two surveys, it was assumed that no change occurred.

These results indicate that a zoning inventory of this type does not become obsolete in a short period of time, even though zoning ordinances are constantly being revised. Therefore this type of zoning inventory represents a useful tool for long-range planning.

TABLE 3.11. I.D. Listing of 1964 Data

ID	M1	M2	M3	AREA	ID	M1	M2	M3	AREA	ID	M1	M2	M3	AREA
10	0.0	0.0	0.0	1.00	580	1.37	0.11	1.34	100.00	1150	0.0	0.0	0.0	1.00
20	0.0	0.0	0.0	1.00	590	1.01	0.08	3.13	100.00	1160	0.0	0.0	0.0	1.00
30	0.0	0.0	0.0	1.00	600	2.67	0.0	22.52	100.00	1170	0.0	0.0	0.0	1.00
40	0.0	0.0	0.0	1.00	610	1.94	0.0	1.77	100.00	1180	0.0	0.0	0.0	1.00
50	0.0	0.0	0.0	1.00	620	2.70	1.27	4.25	100.00	1190	0.0	0.0	0.0	1.00
60	0.0	0.0	0.0	1.00	630	5.16	0.58	3.02	100.00	1200	0.0	0.0	0.0	1.00
70	0.0	0.0	0.0	1.00	640	0.44	0.0	0.0	25.00	1210	0.0	0.0	0.0	1.00
80	0.0	0.0	0.0	1.00	650	6.16	0.0	0.0	25.00	1220	0.0	0.0	0.0	1.00
90	0.0	0.0	0.0	1.00	660	0.76	0.24	0.0	25.00	1230	0.0	0.0	0.0	1.00
100	0.0	0.0	0.0	1.00	670	5.78	3.66	0.23	100.00	1240	0.0	0.0	0.0	1.00
110	0.0	0.0	0.0	1.00	680	3.69	4.99	0.0	100.00	1250	0.0	0.0	0.0	1.00
120	0.0	0.0	0.0	1.00	690	0.45	0.01	0.0	100.00	1260	0.0	0.0	0.0	1.00
130	0.0	0.0	0.0	1.00	700	4.20	3.12	6.52	25.00	1270	0.0	0.0	0.0	1.00
140	0.0	0.0	0.0	1.00	710	5.96	0.48	0.0	25.00	1280	0.0	0.0	0.0	1.00
150	0.0	0.0	0.0	1.00	720	11.04	6.52	0.0	25.00	1290	0.0	0.0	0.0	1.00
160	0.0	0.0	0.0	1.00	730	1.08	0.0	16.12	25.00	1300	0.0	0.0	0.0	1.00
170	0.0	0.0	0.0	1.00	740	13.08	2.56	16.44	25.00	1310	0.0	0.0	0.0	1.00
180	0.0	0.0	0.0	1.00	750	3.13	0.43	1.10	100.00	1320	0.0	0.0	0.0	1.00
190	0.0	0.0	0.0	1.00	760	7.72	3.30	0.77	100.00	1330	0.0	0.0	0.0	1.00
200	0.0	0.0	0.0	1.00	770	0.52	0.32	0.0	100.00	1340	0.0	0.0	0.0	1.00
210	0.0	0.0	0.0	1.00	780	1.36	1.04	5.32	25.00	1350	0.0	0.0	0.0	1.00
220	0.0	0.0	0.0	1.00	790	1.08	2.92	19.92	25.00	1360	0.0	0.0	0.0	4.00
230	0.0	0.0	0.0	1.00	800	3.64	14.84	28.72	25.00	1370	0.0	0.0	0.0	4.00
240	0.0	0.0	0.0	1.00	810	3.88	2.94	17.24	25.00	1380	0.0	0.75	1.50	4.00
250	0.0	0.0	0.0	1.00	820	1.44	1.30	0.0	100.00	1390	0.0	0.0	0.0	4.00
260	0.0	0.0	0.0	1.00	830	1.67	7.32	1.29	100.00	1400	0.0	0.0	0.0	4.00
270	0.0	0.0	0.0	1.00	840	0.27	1.94	0.91	100.00	1410	0.0	0.0	0.0	4.00
280	0.0	0.0	0.0	1.00	850	0.0	0.0	0.0	25.00	1420	0.0	0.0	0.0	4.00
290	0.0	0.0	0.0	1.00	860	0.20	0.0	25.60	25.00	1430	0.0	0.0	0.0	4.00
300	0.0	0.0	0.0	1.00	870	4.08	3.40	19.08	25.00	1440	0.0	0.0	0.0	4.00
310	0.0	0.0	0.0	1.00	880	11.04	4.84	2.80	25.00	1450	0.0	0.0	0.0	4.00
320	0.0	0.0	0.0	4.00	890	1.64	4.08	5.44	25.00	1460	0.0	0.0	45.00	4.00
330	0.0	0.0	0.0	4.00	900	3.36	10.24	49.58	25.00	1470	0.0	0.0	0.0	4.00
340	0.0	0.0	0.0	4.00	910	2.37	2.36	3.06	100.00	1480	0.0	0.0	0.0	4.00
350	0.0	0.0	0.0	4.00	920	0.51	2.63	0.04	100.00	1490	0.0	0.0	0.0	4.00
360	0.0	0.0	0.0	4.00	930	0.0	0.0	0.0	100.00	1500	0.0	0.0	0.0	4.00
370	0.0	0.0	0.0	4.00	940	6.40	9.68	28.68	25.00	1510	0.0	0.0	0.0	4.00
380	0.0	0.0	0.0	4.00	950	3.20	3.92	33.96	25.00	1520	0.0	0.0	0.0	4.00
390	0.0	0.0	0.0	4.00	960	5.88	15.20	5.08	25.00	1530	0.0	0.0	0.0	36.00
400	0.25	4.00	20.75	4.00	970	8.30	0.28	3.84	25.00	1540	0.0	0.0	0.0	100.00
410	0.0	0.0	0.0	4.00	980	0.16	0.0	0.0	100.00	1550	2.28	0.0	1.60	25.00
420	0.0	0.0	0.0	4.00	990	0.0	0.0	0.0	100.00	1560	0.0	0.0	0.0	25.00
430	0.0	0.0	0.0	4.00	1000	0.0	0.0	0.0	100.00	1570	0.0	0.0	0.0	25.00
440	0.25	5.75	19.00	4.00	1010	0.0	0.0	0.0	25.00	1580	0.0	0.0	0.0	25.00
450	0.0	0.0	0.0	4.00	1020	0.20	0.0	0.0	25.00	1590	0.0	0.0	0.0	100.00
460	0.0	0.0	0.0	4.00	1030	0.0	0.0	0.0	100.00	1600	0.0	0.0	0.0	100.00
470	0.0	0.0	0.0	4.00	1040	0.0	0.0	0.0	100.00	1610	0.0	0.0	0.0	100.00
480	0.0	0.0	0.0	4.00	1050	0.0	0.0	0.0	100.00	1620	0.0	0.0	0.0	100.00
490	0.0	0.0	0.0	4.00	1060	0.0	0.0	0.0	100.00	1630	0.0	0.0	0.0	100.00
500	0.0	0.0	0.0	4.00	1070	0.0	0.0	0.0	1.00	1640	0.0	0.0	0.0	100.00
510	0.0	0.0	0.0	4.00	1080	0.0	0.0	0.0	1.00	1650	0.0	0.0	0.0	25.00
520	0.34	0.28	6.46	100.00	1090	0.0	0.0	0.0	1.00	1660	0.0	0.0	0.0	25.00
530	0.41	0.1	1.10	100.00	1100	0.0	0.0	0.0	1.00	1670	0.0	0.0	0.0	4.00
540	0.14	0.14	0.46	100.00	1110	0.0	0.0	0.0	1.00	1680	0.0	0.0	0.0	1.00
550	0.10	0.06	0.52	100.00	1120	0.0	0.0	0.0	1.00	1690	0.0	0.0	0.0	1.00
560	2.97	1.19	9.38	100.00	1130	0.0	0.0	0.0	1.00					
570	1.37	0.01	4.13	100.00	1140	0.0	0.0	0.0	1.00					

4. PROJECTING AND DISPLAY OF FUTURE AIR-POLLUTION EMISSIONS

(A. S. Cohen, J. E. Norco, and A. P. Hurter)

4.1 Discussion

The concept of long-range planning with regard to urban systems has led to techniques for estimating future transportation requirements, population migration, industrial growth, and other important parameters related to urban development. Heretofore, little emphasis has been placed on long-range management of the environment and, in particular, the air we breathe.

The methodology presented in this section is an attempt to provide some insight into long-range air resource management, with estimations of future air quality.

The essential components of this computerized package are:

1. A projection model which estimates future emissions from various components of the urban system.
2. A climatology model to produce prevailing meteorological conditions based on historical data.
3. A dispersion and display model for making air quality computations and isopleth maps. (See flow chart, Fig. 4.1.)

Fig. 4.1. Flow Diagram of Air-pollution Projection and Display Model

An additional component, not developed in this program, might be a statistical analysis to interpret and correlate the output for such purposes as assessing various types of control regulations and how they might be revised as the urban system evolves.

This section serves two functions. First, it will acquaint the reader with the three basic submodels used in the package. (These models are described in detail in the appendixes.) Second, it demonstrates that the package is operational by applying it to Chicago for the year 1980.

It is assumed that in 1980 it will be illegal to burn fuels with a sulfur content greater than 1.5%.

The analysis includes the development of an annual emission inventory by source type, isopleth maps for "highly probable" combinations of meteorological conditions, an "expected" isopleth map, and air-pollution profiles.

4.2 Projection Model

An essential feature of many air-pollution decision-making models is an emission inventory. Many techniques, such as the rapid survey (Ozolins and Smith, 1966) and the permit system (Croke, Roberts, *et al.*, to be published), have been devised for collecting and processing the data required to develop an emission inventory. These data include housing inventories, fuel consumption, land use and intensity, and emission controls. Present-day emission inventories can be readily developed, but few regions have enough historical data to formulate past inventories.

Continuous changes in the urban system, such as industrial migration, fuel switching, urban renewal, and new transportation facilities, make present-day emission inventories obsolete in a relatively short period of time (one or two years). It should be obvious that to assess the air quality of a region in future years, a present-day emission inventory is insufficient. Because of the lack of adequate historical data, time-series projections of emissions are not possible. The projection model developed for this project generates future emission inventories using only available or readily obtainable data.

A base year is selected to develop an emission inventory. (This may be a present-day inventory.) Future inventories are generated using regional growth rates, fuel conversion expectations, new construction plans, etc. These parameters are developed independently. Growth is assumed to occur exponentially, with appropriate capacity restrictions imposed.

The projection model is divided into four major sections. These sections are designed to independently project emission from residential, industrial/commercial point and area sources, and utility sources.

Residential sources are aggregated and treated as area sources. For the Chicago demonstration, three classes of living units were considered; single-family units, two- to 19-family units, and units for 20 or more families. For each square-mile grid, a housing inventory was developed. This included the number of residential buildings in each class using each fuel (coal, oil, or gas). Since housing inventories were available

for two reference years, "growth" rates, reflecting both population shifts and fuel switching, were included using the exponential assumption on growth. Maximum housing densities were imposed for each grid to avoid improbable residential densities. (Since most new residential buildings use gas or electricity in Chicago, these ceilings have little effect on projection of SO_x emissions.)

Industrial sources are categorized into two classes-- "large" and "small" consumers of fossil fuels. For Chicago, 34 industrial firms were classified as "large" sources. They were analyzed individually as point sources. The base-year thermal-energy requirements for these firms are projected forward using regional growth rates of output levels for the appropriate SIC classifications. Each source is surveyed to determine its future fuel-use capability. The expected fuel-use capabilities are used to convert the projected thermal requirements into future fuel-use patterns.

The smaller sources, on the other hand, are aggregated into square-mile area sources. An average regional growth rate and regional fuel use trends are used to make the projections.

Commercial sources are treated in the same way as industrial sources. Growth rates, however, represent new construction rather than output levels. Ten commercial point sources were considered in Chicago, and growth was assumed to be zero. (Since most of the land in Chicago is developed, and clean fuels are used in many newly constructed establishments, this assumption has little effect on SO_x projections.)

The utility sources are treated as point sources; however, output levels of each power plant are not projected independently. Projections are made of total power demand of the system, and allocation to each unit depends on its relative efficiency.

The power company is surveyed to determine future construction, retirement, and fuel-use plans. The Chicago application assumes a 30% downtime on all new construction. Furthermore, the newer power plants are assumed to be the most efficient and are put on-line before the older plants.

A detailed description of the projection model and a discussion of data requirements and sources are presented in Appendix A.

4.3 A Computerized Air-pollution Climatology Data-processing and Display System

The susceptibility of a city or region to high air-pollution dosages is dependent on the frequency of occurrence and persistence of critical combinations of meteorological parameters. Among the most significant

of these are the wind direction and speed, the ambient temperature, the altitude of the mixing-layer lid, and the atmospheric stability (a derived parameter based on observable surface meteorological variables). Accordingly, virtually all atmospheric dispersion models developed to date have, in one way or another, used these as direct inputs. To make effective use of an atmospheric dispersion model as a long-range planning tool, it also must be interfaced with an inventory of data representing the air-pollution climatology of a city or region, as reflected in the probability or frequency of occurrence of critical combinations of meteorological parameters or "met sets." This is the function of the climatology model.

The rationale of the climatology model is identical to that of NAPCA's Air Quality Display Model (AQDM, 1969) which uses a 12-month record of surface meteorological data to generate joint frequency distributions for various met sets. Over 480 possible combinations are included in AQDM input array of "climatology" data. Unlike the AQDM, the climatology model used for this study can be coupled with the integrated-puff atmospheric dispersion model (Roberts, Croke, and Kennedy, 1969) for episodal control. For this type of analysis, the climatology data inventory is used in a somewhat different way than for AQDM. Since episodal control is not the subject of this study, no further discussion of this point is necessary here.

When applied to long-range planning, the climatology computer code displays the frequency of occurrence and persistence of what might be termed routine or normal weather conditions as well as those of episodes. Because the computer code summarizes the frequency of occurrence of a range of persistence intervals (specified by the user), a 1-3-hr persistence frequency report can be generated (the minimum data-reporting interval for most U.S. Weather Bureau stations). This short-persistence report corresponds exactly to the output of the AQDM climatology data-processing routine and can be used in the same way to evaluate the statistical probability of occurrence of selected combinations of meteorological parameters. The resulting evaluation provides the input required for a steady-state dispersion model. This is the way the climatology model will be used in this study.

The climatology code is completely flexible in the sense that the user may select any desired combinations of meteorological parameters, bandwidths, persistence intervals, time intervals, seasons, etc., for display. The code will accept data inventory of any size specified by the user. A 15-year historical weather record for the Chicago Midway Airport weather station was used to test the climatology display system. Weather records for other regions in the form of magnetic tapes are available from the National Weather Records Center. Since very little mixing-layer altitude data are available, a frequency analysis of this parameter is not possible. However, if a data tape were available including this parameter, or data

that could be used to derive this parameter, it could be processed and displayed in exactly the same way as any other item of data. (See Appendix B for a detailed description of this model.)

4.4 Diffusion Model

A model based on the steady-state Gaussian plume is incorporated to compute the pollutant concentrations. (See Appendix C for a detailed description.) In the long-range planning model, the diffusion segment is coded to accept emissions and other source data from both area (square mile) and point sources, in addition to the necessary meteorological variables.

The input wind direction is shifted to the nearest of the 16 compass points for subsequent calculations. At each specified dose point, the contributions of all sources within approximately a 45° angle centered on the wind direction are evaluated. Variable-sized area sources are generated by homogenizing the individual square-mile source to increase the area source size as the distance from the dose point increases (see Fig. 4.2).

Fig. 4.2. Nonuniform Grid for Area-source Emissions. ANL Neg. No. 113-2972.

The temporal scale used depends on the intended use of the output. For example, hourly rates are given if the model is coupled with an atmospheric-dispersion model. The model, however, has the capability of generating daily, monthly, seasonal, or yearly rates.

For the Chicago application, yearly estimates of SO_x emissions for 1970, 1975, and 1980 were made. It is assumed that pollution-control

Concentrations at each dose point are summed for each of three source classes: residential/commercial area sources, industrial area sources, and major point sources.

4.5 The Application of the Planning Model to the City of Chicago

Throughout the development of the planning model, data were gathered for use in testing and demonstrating the model's capabilities. This section describes the application of the model to real world data and the subsequent output.

4.5.1 Emission Inventories

The primary output of the projection model is an emission inventory.

ordinance limiting the sulfur content of all fuels to a maximum of 1.5% is enacted before 1975 and continues through 1980. Furthermore, it is assumed this ordinance has no effect on growth rates.

TABLE 4.1. Yearly SO_x
Emission, tons

1970					
HEAVY MANUFACTURING	RESIDENTIAL	UTILITY	LIGHT INDUSTRY	COMMERCIAL	TOTAL
56,000	69,400	154,200	30,900	11,300	322,100
17 %	22 %	48 %	9 %	4 %	100 %

1975					
32,700	32,900	29,700	17,000	6,800	119,100
27 %	28 %	25 %	14 %	6 %	100 %

1980					
35,900	27,300	10,600	19,800	6,800	100,400
36 %	27 %	11 %	20 %	6 %	100 %

Table 4.1 gives estimates of total yearly emissions. The aggregate change in emissions for heavy and light manufacturing sources represents a combination of three major changes: 1) the pollution-control ordinances, 2) fuel switching, and 3) growth. The first two tend to reduce emissions; the third increases emissions. The large drop in SO_x from 1970 to 1975 can be attributed to the control ordinance, since much of the incentive for fuel switching was created by the ordinance. The fuel

switching, plus the lower sulfur content, resulted in the estimated reduction. Some of the gains, however, were offset by the projected growth in manufacturing activity. This is demonstrated clearly by comparing emissions in 1975 to those in 1980. SO_x levels are rising again, because additional fuel switching does not compensate for increased manufacturing activity.

Another interesting point concerning industrial sources is the increased percentage contribution to total city emissions made by these sources. Unless much of the manufacturing activity moves out of Chicago, this trend will continue.

The emission figures for heavy manufacturing represent 34 of the larger manufacturing firms in Chicago. Of these, 23 responded to the future fuel-use survey. For the other sources, it was assumed present fuel-use patterns would continue.

The decrease in residential emissions from 1970 to 1975 can be attributed to a combination of two factors. Of course, the sulfur ordinance reduced SO_x emissions, but more importantly, the use of coal for residential space heating is on the decline. This rate of decline might be expected to increase because of the ordinance, but without any way to project this change, the assumption that past trends would continue at the same rate was applied.

The greatest change in SO_x emissions, however, cannot be attributed to any of the factors discussed thus far. The greatest change is due to "industrial migration." The migration of power generation from Chicago over the 10-year period, 1970-1980, would cut SO_x emission almost in half without employing any pollution controls. (It is, however, possible that the rate of migration could be affected by the ordinance.)

Two very important qualifications must be placed on these findings. First, the rate of emissions in Chicago from power generation is very sensitive to the utilities' construction timetable. Second, the change in emissions does not represent a total reduction, but rather a transfer of emissions to other parts of Illinois. If the model were applied to the Chicago Air Quality Control Region, the decline in emissions from utilities would not be as sharp.

Because of a lack of data, it was assumed that there would be no change in commercial activity over the next 10 years. Thus, the change in emissions from commercial sources for 1970 to 1975 represents the effects of the control ordinance and fuel switching only. The lack of change from 1975 to 1980 is a result of the no-growth assumption.

For the entire city, emissions are expected to be reduced quite considerably in the next five years and are expected to remain relatively stable until 1980. Emissions will probably rise slightly after 1980, because the rate of growth in manufacturing activity is greater than the rate of decline in the use of coal in residences. However, emissions are not expected to ever reach the levels of 1970, provided an adequate supply of low sulfur fuels remains and power generation is located outside the city.

4.5.2 Climatology

The climatology code was used to generate frequencies of met sets for each season according to the breakdown of Midway Airport weather variables listed in Table 4.2.

TABLE 4.2. Midway Airport Weather Variables

		Winter (D J F)	Spring (M A M)	Summer (J J A)	Fall (S O N)
Temp Band, °F	1	≤20(13)	≤40(35)	≤65(62)	≤45(40)
	2	21-30(25)	41-50(46)	66-73(70)	46-55(51)
	3	>30(37)	>50(60)	>73(80)	>55(61)
Stability-class Band (Turner Class)	1	1-3(2)	1-3(2)	1-3(2)	1-3(2)
	2	4	4	4	4
	3	5	5	5	5
Wind-speed Band, mph	1	≤6(4)	≤6(4)	0-4(3)	0-5(4)
	2	7-12(9)	7-12(9)	5-8(6)	6-9(7)
	3	>12(15)	>12(15)	>8(10)	>9(11)
Wind-direction Band, 16-point compass	1	N-NE(NNE)	NNW-NNE(N)	N-NE(NNE)	N-NE(NNE)
	2	ENE-SE(ESE)	NE-ESE(ENE)	ENE-ESE(E)	ENE-ESE(E)
	3	SSE-SSW(S)	SE-S(SSE)	SE-S(SSE)	SE-S(SSE)
	4	SW-W(WSW)	SSW-WSW(SW)	SSW-WSW(SW)	SSW-WSW(SW)
	5	WNW-NNW(NW)	W-NW(WNW)	W-NNW(NW)	W-NNW(NW)

The value in parentheses indicates the numerical value used in the diffusion-model computations to represent a band.

The rationale for choosing these bands was to:

1. Keep this total number of combinations to a reasonable level (for conservation of computer time). This particular breakdown develops 135 met sets, all of which have nonzero frequencies.
2. Tailor the bands to each season.
3. Provide roughly an equal number of observations in each band for each individual variable. This was accomplished with the aid of a climatological summary (Moses and Bogner, 1967).

The value of the mixing height chosen depended on the stability class, according to the following schedule:

<u>Stability Class</u>	<u>Mixing Height</u>
1-3	Climatological value
4	50% less than the climatological value or 100 m, whichever is greater
5	100 m

The climatological value is the average afternoon mixing depth, as tabulated by Holzworth (1964). The values used in this study were developed from data acquired from the ESSA-EMSU balloon soundings taken at Chicago's Midway Airport. Based on the above criteria, the mixing depths used in the dispersion model are:

<u>Stability Class</u>	<u>Mixing Height, ft</u>			
	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
1-3	2300	4100	4775	3600
4	1150	2050	2400	1800
5	330	330	330	330

Some results of the climatology code are given on the isopleth maps discussed in Section 4.5.3 below.

4.5.3 Isopleth Maps

The basic output mode of the planning model is the isopleth map. For the Chicago test case, the ground-level concentrations developed from

the projected emissions were calculated at every node point on a one-square-mile gridwork. This array was used by a plotting package (incorporated in the model) to plot isopleths of SO_2 on an IBM 2280 film plotter. The isopleth maps (on a continuous roll of unsprocketed film, approximately $1\frac{3}{8}$ in. wide) are projected and overlayed with the city grid to produce pictures such as those in Fig. 4.3. In all the isopleth figures, three concentration levels are depicted; 0.01, 0.05 and 0.1 ppm. A line-density scheme is incorporated to determine the levels. The middle isopleth level (0.05) is always plotted with a heavy line density; the other two are light. This technique enables one to determine the line value at a glance. If, for instance, a light line is observed within a heavy line, it necessarily is a 0.1-ppm line, or if a light line stands alone, it must be a 0.01-ppm line, and so on.

In addition to the individual met-set plots, an overall expected isopleth map can be produced for each season. This is accomplished by computing at every receptor point the sum of the concentrations for all met sets weighted by their respective frequencies. Expected isopleth maps for the winter seasons are shown in Figs. 4.4-4.6. The expected winter isopleths for 1970 and 1975 are included for comparative purposes. The model is coded to handle and plot separately the isopleths for source classes such as residential/commercial area sources, industrial area sources, or major point sources.

4.5.4 Pollution Profile

The maps in Figs. 4.3-4.6 are not direct outputs of the dispersion model. Rather, they are generated from an array of ground-level concentrations as shown in Fig. 4.7. (The outline of Chicago was superimposed onto the array using a transparent overlay.) These data can be used for many types of analyses. For example, pollution-profile analyses are easily performed.

A profile is a means of "measuring" ground-level concentrations on an areal rather than a point scale. It generates the percentage of land area which is below any concentration level for a given set of meteorological conditions. The analysis can be performed for the entire region or for a few known trouble spots.

The approach is similar to the Monte Carlo sampling technique used in many land-use studies and described in detail in Section 3.3.3. The difference is that receptor points in the region are not randomly selected. Although random selection is conceptually possible, the dispersion code does not have this capability. The pollution profile is essentially a cumulative frequency distribution of ground-level concentrations in the region. If only a few areas are being analyzed, then the computations can be performed by hand, as was the one demonstrated below.

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Fig. 4.3. Isopleth Maps for 1980

ANL Neg. No. 113-3438-5 Rev. 1

Fig. 4.3 (Contd.)

ANL Neg. No. 113-3438-1 Rev. 1

Fig. 4.3 (Contd.)

Fig. 4.3 (Contd.)

Fig. 4.3 (Contd.)

Fig. 4.3 (Contd.)

ANL Neg. No. 113-3438-2 Rev. 1

Fig. 4.3 (Contd.)

ANL Neg. No. 113-3438-3 Rev. 1

Fig. 4.3 (Contd.)

ANL Neg. No. 113-3438-9 Rev. 1

Fig. 4.3 (Contd.)

Fig. 4.3 (Contd.)

ANL Neg. No. 113-3488-8 Rev. 1

Fig. 4.3 (Contd.)

Fig. 4.4. Isopleths Drawn from Frequency-weighted Concentrations for the Winter Season 1970. ANL Neg. No. 113-3438-15 Rev. 1.

Fig. 4.5. Isopleths Drawn from Frequency-weighted Concentrations for the Winter Season 1975. ANL Neg. No. 113-3438-14 Rev. 1.

Fig. 4.6. Isopleths Drawn from Frequency-weighted Concentrations for the Winter Season 1980. ANL Neg. No. 113-3438-13 Rev. 1.

The data in Fig. 4.7 were used to develop the isopleth in Fig. 4.3a. The frequency of the met set used is 3.3% or about 72 hr during the spring months. However, because the temperature is 35°F, it is most likely that these conditions occur in March. From the profile in Fig. 4.8, it can be seen that about 97% of the City of Chicago in 1980, will have concentrations below 0.10 ppm whenever these met conditions hold. In addition, the profile for the 12-square-mile area on the southeast corner of the city shows that only 83% of this area is below 0.10 ppm. These percentages represent approximately 7.2 and 1.6 square miles, respectively.

The fixed number and location of receptor points reduce the accuracy of the results as the size of the area being studied is decreased. However, accuracy could be maintained by using a variable number of receptors and choosing their location within the area randomly. This is true even if a single square mile is of interest.

An expected profile and a profile of expected concentrations can also be developed. The expected profile is calculated by multiplying each individual profile by its probability of occurrence, i.e., the frequency of the associated met set, and summing over all met sets. On the other hand, the profile of the expected concentration is calculated by multiplying the concentrations at each point by the probability of its occurrence, summing over all met sets, and developing the profile of these expected values. (The expected isopleth is developed the same way). A simple example will demonstrate the differences.

Assume the study region has four receptors and three possible met sets as follows:

	0.01	0.02		0.12	0.10		0.03	0.05
(1)			(2)			(3)		
	0.03	0.04		0.12	0.11		0.07	0.10

with probabilities of occurrence of 0.55, 0.05 and 0.40, respectively. For this region, the expected profile is given in Fig. 4.9, and the profile of expected concentrations in Fig. 4.10.

As a sample calculation for developing the expected profile, consider the expected land area with concentrations equal to or less than 0.10 ppm. The individual profiles shows 100, 25, and 100% of the land area in this range. Multiplying these by their associated probabilities of occurrence and summing over all met sets gives

$$0.55(100) + 0.05(25) + 0.40(100) = 95.75\%.$$

Therefore, 95.75% of the land area can be expected to experience 0.10 ppm SO_x or less at any random time.

Fig. 4.8. Pollution Profiles

Fig. 4.9. Expected Profile

Fig. 4.10. Profile of Expected Concentrations

The profile of expected concentrations is developed from the expected concentrations at each receptor. These are 0.01, 0.04, 0.05, and 0.07. Thus, 100% of the land area has expected concentrations of 0.07 ppm or less.

Note the difference in the statement of results for the two profiles. The expected profile gives results for cumulative land areas. The specific points experiencing high concentrations differ with each met set. For small areas, however, this profile is an excellent measure of air quality, since the areas of poor air quality are generally close to each other.

The profile of expected concentrations quickly indicates if any specific points consistently experience poor air quality. These points can be identified from the array of expected concentrations.

4.6 Validation of the Projection Model

The validation of analytic models is an important step in their development. Projection models can be validated by applying the model to the past and projecting present-day conditions. For the air-pollution projection model, this type of analysis was not possible because of the lack of historical data. Furthermore, historical information used to develop trends cannot be used for validating the model.

An alternative is to apply the model now and wait a few years to see if the projections were accurate. This is obviously not a reasonable approach for a model that is needed today.

Although validation is not possible, dynamic urban-system models can be used effectively for long-range decision making. Estimates of future air quality in a region, based on present trends, can be useful even if trends do change. The usefulness of such models in long-range planning was demonstrated in the field of transportation planning. The major shortcomings of the urban models were not in their inability to be validated or in their predictive capabilities, but rather in their data requirements. The air quality projection model was designed to use a limited amount of data in an effort to avoid this shortcoming.

Often the ability to determine the cause of variations between estimated and actual results is more important than having highly accurate predictions. The use of the projection model does not end when long-range decisions are made. Decisions should always be followed up with an evaluation of their effectiveness. If expected results do not occur, it is possible to use the projection model to determine why variation occurred. Comparisons of the trend estimates with actual trends may single out major discrepancies. Based on these results, a new strategy may be formulated.

Without the projection model, this disaggregation of the effects of control decisions cannot be performed.

Although validation is preferred, it is not always possible in the field of urban modeling. More importantly, it is not always necessary for the effective utilization of the models for both decision making and decision evaluation.

APPENDIX A

A Computerized Model for the Projection
of Future Air-pollution Emissions

(A. S. Cohen and A. P. Hurter)

1. Description of Projection Model1.1 Residential Sources

Two measures of residential accommodations are used:

Dwelling Unit (DU): A room or group of rooms (1) occupied or intended for occupancy as separate living quarters by a family of one or more persons or by a group of persons living together as a household, and (2) with cooking facilities, either private or shared.

Residential Building: A structure containing one or more DU's and having at least two outside walks. It may also contain one or more nonresidential units and may be divided from other structures by party walls on one or two sides. Its "size" is measured by the number of DU's it contains.

Future residential emission rates and stack heights are projected from estimates of the number of DU's in each square-mile grid* of the region. In addition, estimates must be made of the building sizes associated with these DU's, the type of fuel they use, the properties (e.g., sulfur content) of the fuel, and the efficiencies of the heating plants.

The following notations are used

$CDU(I,J,K)$ = number of coal-burning DU's in year I of size J** in square mile K,

$ODU(I,J,K)$ = number of oil-burning DU's in year I of size J in square mile K,

$GDU(I,J,K)$ = number of gas-burning DU's in year I of size J in square mile K,

$PPC(I)$ = percentage of pollutant in coal used in year I,

$PPO(I)$ = percentage of pollutant in oil used in year I,

$PPG(I)$ = percentage of pollutant in gas used in year I,

CFC = conversion factor for coal,

CFO = conversion factor for oil,

*Any grid system could be used.

**"Of size J" will mean that the DU's are located in a residential building of size J.

CFG = conversion factor for gas,

$C(J,K)$ = rate of change in the number of DU's of size J in cell K burning coal, in percent per year,

$O(J,K)$ = rate of change in the number of DU's of size J in cell K burning oil, in percent per year,

and

$G(J,K)$ = rate of change in the number of DU's of size J in cell K burning gas, in percent per year.

The basic estimating equation in this model, illustrated using coal, is

$$CDU(2,J,K) = CDU(1,J,K)[1 + C(J,K)]^{t_2 - t_1}.$$

The notation t_2 stands for the second reference year being considered, and t_1 for the first year. The number of coal burning DU in year 2 of size J in cell K is equal to the number in year 1 multiplied by the "growth" factor $(1 + C)$ raised to a power to measure the time interval between years, $t_2 - t_1$. The expression is directly analogous to compound-interest calculations at a fixed rate of annual interest. Written another way,

$$C(J,K) = [CDU(2,J,K)/CDU(1,J,K)]^{1/(t_2 - t_1)} - 1, \quad (1)$$

$$O(J,K) = [ODU(2,J,K)/ODU(1,J,K)]^{1/(t_2 - t_1)} - 1, \quad (2)$$

and

$$G(J,K) = [GDU(2,J,K)/GDU(1,J,K)]^{1/(t_2 - t_1)} - 1. \quad (3)$$

These three equations incorporate the basic assumption of the model. Their validity requires a degree of stability in fuel usage and in the growth of dwelling units over the time period under study ($t_2 - t_1$). This is not a stability in absolute numbers, but rather in the rate of change of the numbers. In the three equations to follow, this assumption is extended to encompass the time period from t_1 , through t_2 to t_3 .

$$CDU(3,J,K) = [CDU(2,J,K)][1 + C(J,K)]^{t_3 - t_2}, \quad (4)$$

$$ODU(3,J,K) = [ODU(2,J,K)][1 + O(J,K)]^{t_3 - t_2}, \quad (5)$$

and

$$GDU(3,J,K) = [GDU(2,J,K)][1 + G(J,K)]^{t_3 - t_2}. \quad (6)$$

These six equations are designed to be used with two base data points (t_2 and t_1) to calculate the growth rates $C(J,K)$, $O(J,K)$, and $G(J,K)$ for all

J and K. The growth rates, in turn, are used to estimate the number of DU's of each fuel type and size class in each area element in some other year, t_3 .

To use an extrapolative expression of this kind in a computerized model, we must provide for the "saturation" of a given area element. Therefore, residential growth is constrained by a maximum density factor for each grid. Furthermore, in any newly developed area, care should be taken when applying these equations. The growth rates would be misleading if grid K was farm land or a low-density area in year t_1 and a high-density area in year t_2 . For such grids, future development plans should be studied.

The next phase of the model attempts to convert the estimates of Eqs. 4-6 into the quantity of fuel consumed of each type. Let

$QC(J)$ = the quantity of coal consumed yearly by a DU located in a residential building of size J.

$QO(J)$ and $QG(J)$ are similarly defined for oil and gas, respectively. Then,

$$TQC(I,J,K) = CDU(I,J,K) \times QC(J), \quad (7)$$

$$TQO(I,J,K) = ODU(I,J,K) \times QO(J), \quad (8)$$

and

$$TQG(I,J,K) = GDU(I,J,K) \times QG(J), \quad (9)$$

where TQC , TQO , and TQG are the total quantities of coal, gas, and oil consumed in year I by dwelling units of size J located in grid K. The values of QC , QO , and QG should be functions of the ambient temperature of the study region and the average efficiencies of the heating plants used in each size building.

The quantity of pollutant produced when a given quantity of each kind of fuel is burned depends upon the chemical composition of the fuel being considered and the burner efficiencies. The estimate of the chemical composition of the fuels and the relationship between the composition of the fuel and the tons of pollutants emitted are included in the factors PPC , PPO , PPG , CFC , CFO , and CFG .

Let,

$PC(I,J,K)$ = tons of pollutant emitted in year I by buildings of size J in cell K burning coal,

$PO(I,J,K)$ = tons of pollutant emitted in year I by buildings of size J in cell K burning oil,

and

$PG(I,J,K)$ = tons of pollutant emitted in year I by buildings of size J in cell K burning gas.

Then,

$$PC(I,J,K) = TQC(I,J,K)(CFC)[PPC(I)], \quad (10)$$

$$PO(I,J,K) = TQO(I,J,K)(CFO)[PPO(I)], \quad (11)$$

and

$$PG(I,J,K) = TQG(I,J,K)(CFG)[PPG(I)]. \quad (12)$$

From Eqs. 10-12, estimates of annual tonnage of pollutant emission are computed. It follows that the total quantity of pollutant emitted in year I by buildings of size J in cell K is

$$P(I,J,K) = PC(I,J,K) + PO(I,J,K) + PG(I,J,K). \quad (13)$$

To couple this model with an atmospheric dispersion model, the yearly emission rates calculated in Eq. 13 must be converted to hourly rates. The degree-day method is used to decompose the annual tonnages of space heating emissions into hourly rates.

Let

N = the average number of degree days per year in the study region,

$P(I,J,K,T)$ = the hourly emission rate in year I from buildings of size J located in cell K on a day with temperature T,

and

$PHW(J)$ = the percent of the total fuel consumption required for hot water in buildings of size J.

Then, if $T < 65^\circ$,

$$P(I,J,K,T) = \frac{P(I,J,K)}{24} \left\{ [1 - PHW(J)] \frac{65 - T}{N} + \frac{PHW(J)}{365} \right\}, \quad (14)$$

and if $T > 65^\circ$,

$$P(I,J,K,T) = P(I,J,K)PHW(J)/365(24). \quad (15)$$

The size-of-building factor, J, can be translated into a stack-height factor for use in a dispersion model.

1.2 Industrial/Commercial Point Sources

A detailed survey of large industrial and commercial consumers of energy is necessary for the estimation of point-source emissions. If such a survey has not been conducted, it should be initiated following the procedures suggested in ANL's APICOM* (Croke, Roberts, et al. to be published). For the balance of this section, it is assumed that such a survey has been performed and the necessary fuel-consumption data for the base year (year 2) for the M major consumers are available.

The objective of the I/C point-source model is the projection of various pollutant emission rates for each point source in the target year t3. The emission rates for industrial point sources stem from both the industrial production processes and space-heating requirements, while commercial sources have only space- and water-heating requirements.

The formal presentation of the model uses the following notation:

COAL(I,J) = tons of coal consumed in year I by firm J,

OIL(I,J) = gallons of oil consumed in year I by firm J,

GAS(I,J) = millions of cubic feet of gas consumed in year I by firm J,

PPC(I,J) = percentage of pollutant in coal used in year I by firm J,

PPO(I,J) = percentage of pollutant in oil used in year I by firm J,

PPG(I,J) = percentage of pollutant in gas used in year I by firm J,

CFC(I,J) = conversion factor for coal in year I for firm J,

CFO(I,J) = conversion factor for oil in year I for firm J,

CFG(I,J) = conversion factor for gas in year I for firm J,

BTU(I,J) = Btu's of energy consumed in year I for firm J,

CBTU = conversion factor for tons of coal to Btu's,

OBTU = conversion factor for gallons of oil to Btu's,

and

GBTU = conversion factor for millions of cubic feet of gas to Btu's.

*Air Pollution Incident Control Operations Manual.

The energy consumed by firm J in the base year t_2 is calculated as follows:

$$\begin{aligned} \text{BTU}(2,J) = & \text{COAL}(2,J) \times \text{GBTU} + \text{OIL}(2,J) \times \text{OBTU} \\ & + \text{GAS}(2,J) \times \text{GBTU}. \end{aligned} \quad (16)$$

This total energy requirement is next separated into the energy consumed by industrial processes and that consumed by space heating. Conceptually, this separation permits treatment of the seasonality in space heating and manufacturing separately. Space-heating requirements are difficult to estimate and are often unknown by the firms themselves. In many cases, the process requirements far exceed the space-heating requirements, and little error may be introduced by neglecting the latter. In this model, space-heating requirements are not neglected. They are estimated using the peak hourly winter [PWL(J)] and peak hourly summer [PSL(J)] loads, in Btu's, of each point source. If SH(I,J) is defined as the space-heating Btu requirement in year I of firm J, then,

$$\begin{aligned} \text{SH}(I,J) = & [\text{PWL}(J) - \text{PSL}(I)] \times 24 \\ & \times \frac{\text{Average no. of degree days per year}}{65 - (\text{mean low 15-yr avg temp})} \end{aligned} \quad (17)$$

Equation 17 is only applied if there is a "substantial" difference between the winter and summer peak loads, and if this difference is attributed to space heating rather than production variations. If Eq. 17 is not applicable, SH(I,J) is set equal to zero.

It is assumed in Eq. 17 that the peak winter load occurs on a day with the outside temperature equal to the mean low 15-year average temperature. Furthermore, the output of the production process is assumed to be the same when the peak summer load occurs. For commercial sources, the process refers to water heating. However, the above analysis need not be conducted. A given percentage, say 10% of thermal requirements, may be attributed to water heating.

The energy required for the process, PBTU(I,J), becomes

$$\text{PBTU}(I,J) = \text{BTU}(I,J) - \text{SH}(I,J). \quad (18)$$

Let GR(J) be the annual "growth" rate of firm J.* Then the energy requirement for the process in the target year, t_3 , is

$$\text{PBTU}(3,J) = \text{PBTU}(2,J)[1 + \text{GR}(J)]^{t_3 - t_2}. \quad (19)$$

*Growth rates for the industrial class (SIC) of the firm may be used.

There are three important assumptions that lead to Eq. 19. First, the dynamic stability discussed earlier is assumed to exist; i.e., the annual growth rate remains constant throughout the planning horizon. Second, the production relationships relating inputs to output are assumed to be linear, homogeneous functions, so that the rate of growth of output is the same as the rate of growth of energy requirements. Finally, it is assumed that capacity limitations are not binding. Therefore, no upper limits on PBTU(3,J) are required.

None of these assumptions are necessary for estimating future energy requirements. If these assumptions are approximate representations of the real situation, their use greatly reduces the data requirements and, for that reason, they are adopted as general methodology here.

Assuming that space-heating energy consumption is unchanged over the planning horizon, i.e., $SH(2,J) = SH(3,J)$, Eq. 17 generates the energy requirements in t3 for space heating. These estimates of annual space-heating energy requirements for I/C point sources are converted into estimates of monthly and hourly requirements, using the degree-day concept as follows:

$$SH(3,J,K) = SH(3,J) \times \frac{\text{Average no. of degree days in month K}}{\text{Average no. of degree days per year}} \quad (20)$$

and

$$SHHR(3,J,T) = SH(3,J) \times \frac{65^\circ - T}{\text{Average no. of degree days per year}} \quad (21)$$

In Eqs. 20 and 21, $SH(3,J,K)$ represents the space-heating energy consumption in year 3 of plant J in month K, and $SHHR(2,J,T)$ represents the space-heating energy consumption in year 3 of plant J for a day with temperature T° . If T° is greater than 65° , then $SHHR = 0$.

Annual process-energy requirements in t3 are obtained from Eq. 19. These can be converted to monthly process requirements if the seasonality in the production process (if any) is known. The seasonal pattern of production need not be known completely. For example, all that is required is the identity of those months during which the average process-energy requirements are less than one-third of the peak load and the identity of those months for which the average process energy requirements are greater than two-thirds of the peak load for the base year. Then,

$$PBTU(3,J,K) = PBTU(3,J) \times P(K)/(8Q+5R+2S). \quad (22)$$

In this equation, $PBTU(3,J,K)$ is the energy required during year 3, for plant J, in month K; $P(K)$ is the technologically determined weighting factor

associated with the month K (either 8, 5, or 2); and Q , R , and S are the number of months with energy requirements greater than two-thirds of peak, between two-thirds and one-third of peak, and less than one-third of peak, respectively. In writing Eq. 22, we have assumed that on the average, 80% of the peak energy requirement is demanded in those months operating above two-thirds of peak, 50% of peak energy requirement is demanded in those months operating between two-thirds and one-third of peak, and 20% of peak in those months operating below one-third of peak.

These seasonal variations developed through the use of Eq. 22 are estimates based on the previously determined estimate of total annual energy requirements for a particular plant and several additional assumptions. The additional assumption can be summarized by the statement that the determinants of the seasonal pattern in the base year, t_2 , do not change over time. Thus, the proportional distribution of energy requirements over the months in the target year, t_3 , is identical to that of the base year, t_2 . Put in another way, the assumption leading to Eq. 22 subsumes specific assumptions about finished-goods inventory policy, market structure for the firm's outputs and inputs, and other determinants of the seasonal pattern measured in the base year, t_2 .

Hourly loads are assumed to be uniformly distributed throughout the month. Therefore, if $HR(3,J,K)$ is the hourly consumption of energy in year 3, for industry J , in month K , then,

$$HR(3,J,K) = PBTU(3,J,K)/30(24). \quad (23)$$

Now, the energy requirements have been estimated for the target year. The next step in estimating target-year pollution emissions is to convert these energy requirements into fuel-usage estimates. The expected relative proportions of the energy requirements supplied by coal, oil, and gas, when fuel conversion* does not take place, for the year t_3 is assumed to be known. These are represented by $PROC(3,J)$, $PROQ(3,J)$, and $PROG(3,J)$, respectively. Industrial plants often have the technological ability to convert from one fuel to another, i.e., dual fuel capacity, for both space-heating and process-energy requirements. These two technologically based variables are defined as follows:

$PGP(I,J)$ = the proportion of the process-energy requirements in year I for plant J which could be met using gas,

and

$PGSH(I,J)$ = the proportion of the space-heating energy requirements in year I for plant J which could be met using gas.

The extent to which a particular plant can convert to gas in the target year, t_3 , is assumed to be known.

*Refers to dual-fuel gas conversion.

Changes in fuel-use patterns for individual plants between the base year and the target year are difficult to predict. In contrast, the growth trends used in Eq. 19 rely on the averaging of actions of numerous customers, and these trends may reasonably apply to individual firms in the same industry. However, the application of national or local trends in fuel conversion to individual firms seems less reasonable, since the individual peculiarities of the production function and location of each individual firm would play a key role in determining fuel-use patterns. For example, legal controls on air pollution might drastically alter fuel-use patterns. For these reasons, each firm studied should be surveyed to determine any future plans concerning the proportional use of coal, oil, and gas, and conversion capabilities. If no changes are being planned, it will be assumed that in t_3 the fuel-use proportions and gas-conversion capabilities will be the same as those observed for the base year t_2 . If changes are being contemplated, then it is assumed that these changes are appropriate for year t_3 .

Gas conversion is used in industry because of the seasonality of gas prices. When residential and commercial space-heating requirements are low, gas is available to industry at dump rates, and conversion to gas takes place. On the other hand, in the winter months the price of gas to industries is high, compared to coal and oil, because of limited supplies. Therefore, the use of gas is uneconomical. In many regions, gas is simply not available to industries during the heating season. For these reasons, it is necessary to define a threshold temperature for each industry, $TEMP(J)$, as the temperature for which company J considers it economical to switch to gas. Surprisingly enough, experience has shown that the local gas company has a better idea of each industry's threshold temperature than the firm itself. If, however, these data are not available, the threshold temperature is assumed to be $45^\circ F$.

Assuming that each firm will use its full capacity to convert to gas whenever the temperature is above $TEMP(J)$, hourly fuel consumption can be calculated. If the temperature, T , of any day in month K is greater than or equal to $TEMP(J)$, then the total hourly gas consumption due to conversion is

$$\overline{GAS}(3,J,T,K) = \frac{PBHR(3,J,K)PGP(3,J)}{GBTU} + \frac{SHHR(3,J,T)PGSH(3,J)}{GBTU} \quad (24)$$

If the temperature is less than $TEMP(J)$, then gas consumption due to conversion is zero; i.e., $\overline{GAS}(3,J,T,K) = 0$.

The total hourly energy requirement has been predicted, and so has the number of Btu's supplied by gas conversion, i.e., $\overline{GAS}(3,J,T,K) \times GBTU$. The difference between these two quantities is the number of Btu's for the particular plant and day, supplied by oil, coal, and gas.* The total number

*Noninterruptible gas.

of Btu's multiplied by the fraction PROC and PROO yields the Btu's supplied by coal and oil which is converted to the quantity of coal and oil used through the factors, CBTU and OBTU, as illustrated in

$$\text{COAL}(3,J,T,K) = \frac{[\text{PBHR}(3,J,K) + \text{SHHR}(3,J,T) - \overline{\text{GAS}}(3,J,T,K) \times \text{GBTU}][\text{PROC}(3,J)]}{\text{CBTU}} \quad (25)$$

and

$$\text{OIL}(3,J,T,K) = \frac{[\text{PBHR}(3,J,K) + \text{SHHR}(3,J,T) - \overline{\text{GAS}}(3,J,T,K) \times \text{GBTU}][\text{PROO}(3,J)]}{\text{OBTU}} \quad (26)$$

Similarly, total hourly consumption of gas is calculated using

$$\text{GAS}(3,J,T,K) = \overline{\text{GAS}}(3,J,T,K) + \frac{[\text{PBHR}(3,J,K) + \text{SHHR}(3,J,T) - \overline{\text{GAS}}(3,J,T,K) \times \text{GBTU}][\text{PROC}(3,J)]}{\text{GBTU}} \quad (27)$$

The pollution emitted per hour on a day with temperature T in month K from coal, oil, and gas can now be calculated using

$$\text{PC}(3,J,T,K) = \text{COAL}(3,J,T,K) \times \text{PPC}(3,J) \times \text{CFC}(3,J), \quad (28)$$

$$\text{PO}(3,J,T,K) = \text{OIL}(3,J,T,K) \times \text{PPO}(2,J) \times \text{CFO}(3,J), \quad (29)$$

and

$$\text{PG}(2,J,T,K) = \text{GAS}(3,J,T,K) \times \text{PPG}(3,J) \times \text{CFG}(3,J), \quad (30)$$

respectively. The total pollution emitted on a day with temperature T in month K is

$$\text{P}(3,J,T,K) = \text{PC}(3,J,T,K) + \text{PO}(3,J,T,K) + \text{PG}(3,J,T,K). \quad (31)$$

For most commercial sources, this analysis is too detailed. However, growth rates and gas-conversion capabilities can be set at zero. Thus, only fuel-use conversions are considered.

1.3 Industrial/Commercial Area Sources

In some regions, the number of industrial plants and commercial establishments is small enough to make a 100% survey practical, and therefore all these sources can be treated as point sources. However, as the size of the study region increases, the number of firms in the area will most likely increase. Although a 100% sample is always feasible, it is not always practical. There is a point at which the accuracy gained from a complete survey is not worth the additional time and expense of making the survey. Therefore, in larger regions some form of aggregation is recommended.

The locations of these sources are restricted by the local zoning ordinances. Thus, only those areas zoned for manufacturing or commercial/business activities need be considered. It is probable that exceptions are made and some firms are not located according to zoning regulations; however, these exceptions should be small in number and can be neglected without serious error.

The model will be presented in terms of industrial sources; the commercial source model is identical.

It is assumed that the "aggregate production functions" are homogeneous of degree one. Therefore, all estimates can be made from fuel-consumption data rather than output data, since they are directly proportional. The following information is assumed to be available (with I = year and J = fuel type):

1. The total fuel usage by the industrial sector of the region for year 2, FUEL(2,J).
2. The percent of pollutant in each fuel J in year I, PP(I,J).
3. The conversion factor of each fuel for the given pollutant in year I, CF(I,J).

Furthermore, from the I/C point source submodel, the following information can be generated:

4. The total fuel usage by large industries (point sources) in the region for year 2, PS(2,J).
5. The average percent of the total fuel usage used for processing, PPRO. [(1 - PPRO) equals the percent of fuel used for space heating.]

First, the fuel usage of the aggregated sources, SI(2,J), is calculated for the base year by subtracting the fuel used by the larger firms from the total usage,

$$SI(2,J) = FUEL(2,J) - PS(2,J). \quad (32)$$

It is assumed that a rate of change in the use of each fuel for industries, RC(J), is known. This can be obtained from fuel-consumption data for the region.* The usage of each fuel by the aggregated firms can be projected for year 3:

$$SI(3,J) = SI(2,J)[1 + RC(J)]^{t_3 - t_2}. \quad (33)$$

*If historical data are available, an equation similar to Eqs. 32-34 in the residential model can be used. Furthermore, if percentage usage trends are known, total Btu requirements can be projected using an economic growth rate, and the fuel-usage figure can be obtained by using the projected percent usage of each fuel.

To obtain the total emissions in any year, i.e., $P(I)$, the simple conversion equation used in the other models is applied; i.e.,

$$P(I) = \sum_J SI(I,J) \times PP(I,J) \times CF(I,J). \quad (34)$$

With the assumptions that the location of industrial-area sources can be found from zoning regulations, the total emission figures just calculated can be distributed to each square-mile grid as follows:

$$P(I,K) = PM(K) \times P(I), \quad (35)$$

where $P(I,K)$ = the pollution emitted in year I from grid K , and $PM(K)$ is the proportion of the total city-wide area zoned for manufacturing that is contained in grid K . In other words, industrial area-source pollution is distributed over the city grids in proportion to the grid's share of the total area zoned for industry.

Implicit in Eq. 35 is the assumption that the small firms are uniformly distributed throughout the areas zoned for manufacturing. If some of the area zoned for manufacturing is vacant or unusable land and/or water, then this land should not be considered in estimating $PM(K)$'s. If new industry or expansion is planned for the study period, then this information is incorporated into the projection of year t_3 emissions for the grids involved.

The yearly emission rates per square-mile grid, which are now known, must be converted into estimates of hourly emissions. The yearly emissions are first divided into those related to the generation of process energy and those related to space heating.

Assuming the same percentage of fuel is used for the manufacturing process in small and large industries, the emissions in year I in grid K due to manufacturing processes of small industries is

$$PMAN(I,K) = P(I,K) \times PPRO, \quad (36)$$

and the emissions due to space heating is

$$PSH(I,K) = P(I,K) - PMAN(I,K). \quad (37)$$

The aggregation of firms over the city tends to cancel out the seasonal effects from the production processes. Therefore, hourly emissions in year I for grid K due to industrial processing activities are

$$PPH(I,K) = PMAN(I,K)/365(24). \quad (38)$$

To obtain hourly emission from space heating, the degree-day formula is used. For a day with temperature T , the hourly emission in year I in grid K is

$$PSHH(I,K,T) = PSH(I,K) \frac{65^\circ - T}{\text{Avg no. of degree days per yr (24)}} \quad (39)$$

If $T > 65^\circ$, then emissions from space heating are set at zero. Finally, the total emission on a day with temperature T is

$$P(I,K,T) = PSHH(I,K,T) + PPH(I,K) \quad (40)$$

1.4 Electric-utility Power-generation Sources

The model for the projection of emission rates by electric power companies, calculates the following in sequence:

1. The total hourly load, i.e., the demand on the power company's system, is estimated.
2. This total load is allocated to the individual power-generating units in the system.
3. The load allocated to each unit is converted into a thermal-input requirement.
4. The thermal input for each unit in study region is converted into a fuel input using projected fuel-use patterns.
5. The fuel usage is converted into emission rates for each unit.
6. The emission from each unit is allocated to each stack in the plants under study.

From the local electric-utility company's daily load charts, a table of average hourly loads as a function of temperature can be generated. The size of these tables can be greatly reduced by using both temperature and hour ranges. Table A.1 represents a sample load-versus-temperature table. Note that three hour ranges and three temperature ranges are used. Furthermore, load patterns change drastically with the seasons; thus a table should be compiled for each season, as shown.

TABLE A.1. Sample Table of Load vs Temperature

Season	Hour Range			Hour Range			Hour Range		
	1	2	3	1	2	3	1	2	3
Winter	4142	6030	6321	4244	6345	6800	4244 ^a	6345	6800
Spring	3855	5737	5780	3685	5577	5471	3803	5883	5700
Summer	3809 ^a	5300	5911	3809	5300	5911	4563	6519	7110
Fall	4062	5980	6337	3846	5840	5836	3882	6223	6342
	$T \leq 49^\circ\text{F}$			$50^\circ \leq T \leq 69^\circ\text{F}$			$T \geq 70^\circ\text{F}$		

^aThis combination of temperature range and season was not observed in data. Therefore, loads per hour range were assumed the same as the $50^\circ \leq T \leq 69^\circ\text{F}$ range loads.

For any temperature range T and season, associated loads for each hour range are obtained from the load versus temperature charts. These loads are then allocated to each unit in the system. The following notation is used:

J = plant index, H = hour-range index,
 U = unit index, T = temperature-range index,
 K = stack index, M = season index,

and

I = year index.

Then,

$L(I,M,J,U,T,H)$ = the average hourly load in year I , season M for plant J to unit U for temperature range T in hour range H ,

$BTU(I,M,J,U,T,H)$ = the hourly thermal input in year I season M for plant J to unit U for temperature T in hour range H ,

and

$A(J,U)$ and $B(J,U)$ = the coefficient of the (assumed) linear production function of unit U in plant J (see Fig. A.1).

Fig. A.1

Gross Thermal Input vs Load, with
 Approximating Line. ANL Neg.
 No. 112-9796.

The assumption of a linear production function with constant input costs (i.e., constant ratio of inputs to outputs and marginal costs) implies that the unit with the lowest marginal cost will be used to capacity before

any other unit is committed for use. This result makes it possible to allocate the total load at any time to each unit in the system.†

For simplicity in notation, assume that a season, temperature range, and hour range have been selected. For the base year, let $L(J,U)$ be the average hourly load allocated to unit U in plant J . Then,

$$L = \sum_J \sum_U L(J,U), \quad (41)$$

such that

$$L(J,U) \leq ML(J,U),$$

where $ML(J,U)$ is the maximum hourly load of unit U in plant J . Furthermore, if unit $\bar{U}$ in plant $\bar{J}$ is less efficient than unit U^* in plant J^* and $L(\bar{J},\bar{U}) = ML(\bar{J},\bar{U})$, then $L(J^*,U^*) = ML(J^*,U^*)$. Also, if $L(J',U') < ML(J',U')$, then $L(J,U) = 0$ for all units that are less efficient than unit U' in plant J' .

In other words, the model ranks each unit according to its efficiency. The most efficient plant is used up to capacity; if demand is not met, the next most efficient plant is used up to capacity; and so on, until demand is met. If all units are used to capacity and demand is not met, it is assumed that power is purchased outside the system.

A single example will help illustrate this procedure. Let $L = 100$ MWe, plant 1 having two units with efficiencies of 95 and 90% with capacities of 50 and 20 MWe, respectively, and plant 2 having one unit with efficiency of 80% and capacity of 50 MWe. Then,

$$L = L(1,1) + L(1,2) + L(2,1),$$

or

$$100 = 50 + 20 + 30.$$

For each unit in a plant located in the study region, the model calculates the thermal input required to meet these loads:

$$BTU(J,U) = A(J,U)L(J,U) + R(J,U). \quad (42)$$

The percentage of each fuel used to satisfy the Btu requirement given by Eq. 42 is known for season M in year I and for temperature range T .

†The system represents all the plants owned by the power company, whether they are located in the study region or not. If the study region's electricity is supplied by more than one company, each company is considered as a separate system and treated independently.

For example, in Chicago many power-generation stations have dual fuel-operational capability. In the summer months, relatively small percentages of coal are burned, because of the availability of gas at low (dump) rates. A dual fuel plant may operate almost exclusively on gas during the summer, except for a 15% nominal coal input required to maintain a protective slag coating on the boiler grates. However, the situation changes when gas becomes more expensive and less available during the winter months; then the utility plants burn coal (or oil) almost exclusively.

Let $PC(J,U)$, $PO(J,U)$, and $PG(J,U)$ be the percentage of coal, oil, and gas used in unit U in plant J for the season, year, and temperature being considered. Then,

$$COAL(J,U) = PC(J,U)BTU(J,U)CBTU, \quad (43)$$

$$OIL(J,U) = PO(J,U)BTU(J,U)OBTU, \quad (44)$$

and

$$GAS(J,U) = PG(J,U)BTU(J,U)GBTU, \quad (45)$$

where $COAL(J,U)$, $OIL(J,U)$, and $GAS(J,U)$ are tons of coal per hour, kgal of oil per hour, and cubic feet of gas per hr used in unit U in plant J ; and $CBTU$, $OBTU$, and $GBTU$ are conversion factors for coal, oil, and gas. If other fuels are used, similar equations would be used for each additional fuel.

The model now computes the pollution emitted from each unit:

$$\begin{aligned} \bar{P}(J,U) = & COAL(J,U) \times PPC(J,U) \times CFC + OIL(J,U) \\ & \times PPO(J,U) \times CFO + GAS(J,U) \times PPG(J,U) \times CFG, \end{aligned} \quad (46)$$

where

$\bar{P}(J,U)$ = emission rate per hour of pollutant from unit U in plant J ,

$PPC(J,U)$ = percent of pollutant in coal used in unit U in plant J ,

$PPO(J,U)$ = percent of pollutant in oil used in unit U in plant J ,

$PPG(J,U)$ = percent of pollutant in gas used in unit U in plant J ,

CFC = conversion factor for coal,

CFO = conversion factor for oil,

and

CFG = conversion factor for gas.

Recall that $\bar{P}(J,U)$ is calculated for each hour range. Let $P(J,U,H)$ represent the average hourly emissions in plant J and in unit U for hour range H . The expected average hourly emissions are calculated using the following equation:

$$P(J,U) = \sum_H N(H)P(J,U,H)/24 \quad (47)$$

In this equation, $N(H)$ is the number of hours in each range, where $\sum_H N(H) = 24$ (see Table A.2).

TABLE A.2. Duration of Hour Range per Season

Season	Hour Range		
	1	2	3
Winter	9	11	4
Spring	9	10	5
Summer	9	6	9
Fall	9	10	5

These emission rates are now distributed to the stacks as follows:

$$P(J,K) = \sum_U W(J,U,K)P(J,U), \quad (48)$$

where $P(J,K)$ is the pollution emitted from stack K in plant J , $W(J,U,K)$ is the unit to stack coupling coefficient (weights) for unit U and stack K , and

$$\sum W(J,U,K) = 1$$

for a given U .

This model is based on the assumption that in year 1, load-versus-temperature charts for each month are known. However, to project loads in the future and to allocate these loads to units the following information is required:

$RG(M)$ = rate of growth per season of the system, i.e., seasonal increase in power demands as a percentage of present demand;

$RE(J,U)$ = rate of change of efficiencies per year of unit U in plant U .

Also, data concerning future plans to build new plants and associated information about unit capacities, efficiencies, and fuel use are required. Plans to phase out existing plants are also needed.

To obtain load-versus-temperature charts in the year t_3 , i.e., the target year, the following equation is used:

$$L(3, \bar{M}, J, U, \bar{T}, H) = L(2, \bar{M}, J, U, \bar{T}, \bar{H}) [1 + RG(\bar{M})]^{t_3 - t_2}, \quad (49)$$

or for season $\bar{M}$, temperature $\bar{T}$, range and hour range $\bar{H}$, the load in year I is

$$L(I, J, U) (1 + RG)^{t_I - t_2}.$$

The load-versus-temperature charts for year t_3 are calculated in the manner just described. Before the model can be applied to calculate emissions, the efficiency of existing units are adjusted as follows:

$$EFF(I, J, U) = EFF(2, J, U) [1 + RE(J, U)]^{t_I - t_2}. \quad (50)$$

With these data and information concerning the efficiencies of newly constructed units, the units are ranked in order of efficiency. Also, all those units scheduled to be phased out during the planning horizon are eliminated from consideration. In other words, it is assumed that present plans will materialize. Furthermore, expected downtime of new plants can be estimated, and their capacities are adjusted downward to account for these occurrences.

After running the model for year t_3 , we may find that abnormal amounts of power are purchased outside the system, i.e., demands are not being met regularly with the proposed new systems. The more efficient units phased out are added back into the system until demands are met "regularly." In this way, parametric studies on the scheduling of future plans are possible.

2. Data Requirements and Sources

2.1 Residential Sources

Three types of basic data are required for the residential model: residential housing inventories; the parameters QC , QO , and QG required to transform the number of DU's using each type fuel to the quantity of fuel consumed; and the conversion factors PPC , PPO , PPG , CFC , CFO , and CFG necessary to convert the quantity of each type of fuel consumed to the amount of each pollutant emitted. The latter two types of data are based upon predictions concerning the "advance" of technology and the availability of resources.

The first type of data required is the number of DU's, of each size, in each square mile of the city, that burn the three types of fuel, i.e., $COAL(I, J, K)$, $OIL(I, J, K)$, and $GAS(I, J, K)$. To be manageable, these data

must be aggregated so that a relatively small number of building size classes are considered. For example, one aggregation might include 1 DU building, 2-3 DU buildings, 4-7 DU buildings, 8-19 DU buildings, 20-59 DU buildings, and over 60 DU buildings. In this case, J would take on one of six values. These data must be collected for at least two years (t_1 , t_2) for use in the model equations 41-43.

Possible sources of these data are the local fuel distributors or utilities. If past data are only available for one year, an independent survey would be necessary to determine the present residential housing inventory. If no past data are available, an alternative means of estimating the future housing inventory must be used. Such an alternative might be based on plans or projections of future land use. Often they include projections of residential densities. Given the local zoning ordinance, the present housing inventory, urban renewal programs, and local trends in fuel usage, the figures on estimated future residential densities could be translated into a future housing inventory.

Projections of the quantity of fuel of each kind burned per year per DU (QC, QO, and QG) are ultimately based upon the number of units of thermal energy (Btu's) required in each size of residential building in order to maintain its temperature at some desired level. The primary sources of this kind of information are utility companies who must collect such data as a part of their market evaluations. Since estimates of similar parameters must play a role in any kind of air-pollution study undertaken, governmental agencies concerned with air pollution in the urban area under consideration may already have estimates of these parameters. For example, Table A.3 was provided by the Chicago Department of Air Pollution Control. The values of the fuel required for water heating can also be obtained from these sources (see Table A.4). The percent of the fuel required for water heating can easily be calculated from the data in these tables.

TABLE A.3^a Quantities of Gas, Oil, and Coal Used Yearly per Dwelling Unit by Different-sized Residential Buildings

No. of Apartments per Building	Gas, ^b cu ft	Oil, ^b gal	Coal, ^b tons
1	140,000 (0.80)	1068 (0.75)	6.48 (0.64)
2 and 3	126,733 (0.80)	965 (0.75)	5.86 (0.64)
4-7	109,840 (0.80)	837 (0.75)	4.78 (0.68)
8-19	95,000 (0.80)	726 (0.75)	4.14 (0.68)
20-59	80,000 (0.80)	610 (0.75)	3.16 (0.75)
60 ⁺	72,000 (0.80)	549 (0.75)	2.84 (0.75)

^aCroke *et al.* (1968).

^bFigures in parentheses indicate efficiencies of the fuel-burning equipment.

TABLE A.4^a Annual Residential Fuel Requirements per Dwelling Unit (DU) for Hot Water

No. of DU's per Building	Gas, ft ³ /yr	Coal, tons/yr	Oil, gal/yr
1-2	3×10^4	1.2	200
3-7	2.5×10^4	1	170
>8	2×10^4	0.8	130

^aCroke *et al.* (1968).

Some fuel distributors may withhold this information because they feel it would injure their competitive situation. In this case, other sources of estimates for QC, QO, and QG must be used. Meteorological data on temperature and wind velocities are available in any urban area. In addition, estimates of the indoor temperatures maintained are also available. If necessary, engineers can estimate the heat losses to be experienced in various-sized residential buildings. These estimates of the rate of heat-energy usage can then be converted to fuel usage of different types. In this way, rough estimates of QC, QO, and QG can be obtained for almost any urban area.

The pollution content of the fuel to be used (PPC, PPO, and PPG) in the year I can be established from expected availability of fuels and the location of the various fuel sources. These estimates must also consider the possibility of emission-control ordinances restricting the pollutant content of fuels used in the area. For example, both Chicago and New York have passed ordinances limiting the sulfur content of fuels burned in the city.

The conversion factors CFC, CFO, and CFG are functions of technology. In the model presented above, technological advances are not considered since they would be extremely difficult to predict. A good source for the values of these parameters is Duprey (1968).

To convert yearly emissions into daily emissions, degree-day data are required. These can be obtained from the U.S. Weather Bureau. Finally, an average stack height can be estimated for each size residential building.

2.2 Industrial/Commercial Point Sources*

The data required by the I/C point-source model all refer to the base year, with the exception of the data related to future conversion plans.

*The data required for industrial sources are considerably more than for the commercial sources. For this reason, this section is written with emphasis on manufacturing. A modified survey approach is suggested for commercial sources.

More reliable estimates of the future might be possible, if data for more than a single historical year were collected. Nevertheless, since a survey is required, the model is developed assuming only data for a single base year are available. Further, the model employs calculations yielding variable values that might have been obtained directly from the industrial firm. However, experience indicated that industrial responses to requests for certain variable values were not likely to be as accurate as calculations of the same values made in the model. In many cases, the firms are simply reluctant to give the desired information to the interviewer. Further, it was found that answers to simple direct questions were more accurate than answers to questions involving calculation on the part of the interviewee.

There is another important reason for using this data format. It is a simple modification of that proposed for developing an emission inventory in the APICOM. Utilization of one set of interviews for both planning and incident-control purposes has the advantage of not trying the patience of the interviewee.

Figure A.2 shows the "emission inventory computer card set" used to obtain some of the data. For a complete description of the survey technique and the associated "permit" system, refer to the APICOM.

From these cards, the following information for the I/C model is extracted:

- Card 1: The location of the point source on the grid system of the region is found using the firm's address and a grid map of the city.
- Card 2: The Standard Industrial Classification (SIC) code is useful if national or regional "growth" rates are used for trend extrapolation.
- Card 3:
 - a. The annual consumption of coal for the base year, $COAL(2,J)$, is given directly.
 - b. The pollutant content of the coal used, $PPC(J)$, can be derived from knowledge of the main source supply.
 - c. The type of burning unit may be used to calculate the pollution conversion coefficient for coal, $CFC(J)$.
- Card 4:
 - a. The annual consumption of oil in the base year, $OIL(2,J)$, is given directly.
 - b. The pollutant content of the oil used, $PPO(J)$, can be derived from knowing the main source of supply.
 - c. The annual consumption of gas in the base year, $GAS(2,J)$, is given directly.

BUILDING DATA (please print all information)		1
COMPANY NAME _____	13 - 32	PHONE _____
COMPANY ADDRESS _____		
(street) 34 - 53	(city) 55 - 64	(zip) 66 - 70
IS ADDRESS SAME AS ON ENVELOPE? YES _____ NO _____		
.		
THESE FORMS PREPARED BY:	_____	_____
	(name)	(address)
	_____	_____
	(title)	(phone)

LAND USE CODE (fill in boxes with most appropriate code numbers)		2																																						
<p>CLASS. CODE</p> <div style="border: 1px solid black; width: 40px; height: 20px; margin: 5px auto; position: relative;"> <div style="position: absolute; left: 5px; top: 5px; width: 15px; height: 10px;"></div> <div style="position: absolute; left: 15px; top: 5px; width: 15px; height: 10px;"></div> </div> <div style="display: flex; justify-content: space-around; font-size: 8px;"> 1011 </div> <p>NUMBER OF DWELLING UNITS (for residential buildings)</p> <div style="border: 1px solid black; width: 100px; height: 20px; margin: 5px auto; position: relative;"> <div style="position: absolute; left: 5px; top: 5px; width: 20px; height: 10px;"></div> <div style="position: absolute; left: 20px; top: 5px; width: 20px; height: 10px;"></div> <div style="position: absolute; left: 40px; top: 5px; width: 20px; height: 10px;"></div> <div style="position: absolute; left: 60px; top: 5px; width: 20px; height: 10px;"></div> </div> <div style="display: flex; justify-content: space-around; font-size: 8px;"> 15161718 </div> <p>TOTAL SQUARE FEET OF FLOOR AREA (commercial and industrial buildings only)</p> <div style="display: flex; justify-content: space-between; font-size: 8px;"> <div style="border: 1px solid black; width: 20px; height: 15px;"></div> <div style="border: 1px solid black; width: 20px; height: 15px;"></div> <div style="border: 1px solid black; width: 20px; height: 15px;"></div> <div style="border: 1px solid black; width: 20px; height: 15px;"></div> <div style="border: 1px solid black; width: 20px; height: 15px;"></div> </div> <div style="display: flex; justify-content: space-around; font-size: 8px;"> 1920212223 </div>	<p>AUXILIARY CODE</p> <div style="border: 1px solid black; width: 30px; height: 15px; margin: 5px auto; position: relative;"> <div style="position: absolute; left: 5px; top: 5px; width: 10px; height: 10px;"></div> </div> <div style="text-align: center; font-size: 8px;">12</div> <p>CODE CATEGORY</p> <table style="width: 100%; border-collapse: collapse; font-size: 8px;"> <tr><td style="width: 5%;">0</td><td>NOT AN AUXILIARY</td></tr> <tr><td>1</td><td>CENTRAL OR ADMINISTRATIVE OFFICE</td></tr> <tr><td>2</td><td>SALES OFFICE</td></tr> <tr><td>3</td><td>RESEARCH AND DEVELOPMENT</td></tr> <tr><td>4</td><td>WAREHOUSING AND STORAGE</td></tr> <tr><td>5</td><td>AUTOMOBILE PARKING</td></tr> <tr><td>6</td><td>MOTOR VEHICLE GARAGE (MAINTENANCE AND/OR STORAGE OF VEHICLES)</td></tr> <tr><td>7</td><td>STEAM AND POWER PLANT</td></tr> <tr><td>8 AND 9</td><td>(OPEN CODES)</td></tr> </table>	0	NOT AN AUXILIARY	1	CENTRAL OR ADMINISTRATIVE OFFICE	2	SALES OFFICE	3	RESEARCH AND DEVELOPMENT	4	WAREHOUSING AND STORAGE	5	AUTOMOBILE PARKING	6	MOTOR VEHICLE GARAGE (MAINTENANCE AND/OR STORAGE OF VEHICLES)	7	STEAM AND POWER PLANT	8 AND 9	(OPEN CODES)	<p>OWNERSHIP CODE</p> <div style="border: 1px solid black; width: 40px; height: 15px; margin: 5px auto; position: relative;"> <div style="position: absolute; left: 5px; top: 5px; width: 15px; height: 10px;"></div> <div style="position: absolute; left: 15px; top: 5px; width: 15px; height: 10px;"></div> </div> <div style="display: flex; justify-content: space-around; font-size: 8px;"> 1314 </div> <p>CATEGORY</p> <table style="width: 100%; border-collapse: collapse; font-size: 8px;"> <tr><td colspan="2">PUBLIC</td></tr> <tr><td style="width: 5%;">11</td><td>FEDERAL</td></tr> <tr><td>12</td><td>STATE</td></tr> <tr><td>13</td><td>COUNTY</td></tr> <tr><td>14</td><td>TOWNSHIP</td></tr> <tr><td>15</td><td>MUNICIPAL</td></tr> <tr><td>16</td><td>SPECIAL DISTRICT</td></tr> <tr><td>19</td><td>OTHER PUBLIC, NEC</td></tr> <tr><td colspan="2">PRIVATE</td></tr> <tr><td>20</td><td>PRIVATE</td></tr> </table>	PUBLIC		11	FEDERAL	12	STATE	13	COUNTY	14	TOWNSHIP	15	MUNICIPAL	16	SPECIAL DISTRICT	19	OTHER PUBLIC, NEC	PRIVATE		20	PRIVATE
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Notes: Card 2 Cols. 10, 11 is the Standard Industrial Classification. This list must be provided in the cover letter or on another computer card (with TAB on left-hand corner; i.e.,). The SIC has been augmented by several new categories: Purely Residential (10), Purely Commercial (11), Combined Commercial and Residential (12), Electric Utility (40), Other Utilities (41).

Fig. A.2. Emission Inventory Computer Card Set

BOILER/BURNER - COAL DATA 3

NUMBER OF BOILERS WHICH CAN BURN COAL OR DUAL GAS AND COAL _____
 (if none, leave remainder of card blank) 13-14

TOTAL CONSUMPTION BETWEEN JAN. 1, 1969 AND DEC. 31, 1969

_____ \$ _____
 (tons of coal) 16-22 (cost of whole amount) 24-30

MAIN SOURCE AREAS OF COAL (check all applicable)

ILL.₃₂() E. KY.₃₃() W. KY.₃₄() IND.₃₅() OHIO₃₆()

W. VA.₃₇() PENN.₃₈() OTHER₃₉()

_____ (list other main source areas)

WHAT TYPES OF BURNING UNITS (check all applicable)

UNDERFED ₄₁() SPREADER₄₂() CYCLONE₄₃()

HAND FIRED₄₄() PULVERIZED₄₅()

BOILER/BURNER - OIL, GAS DATA 4

FUEL OIL BURNED BETWEEN JAN. 1, 1969 AND DEC. 31, 1969

GRADES	1	2 - 4	5 - 6
TOTAL GALLONS	13-14	21-27	29-35
COST OF WHOLE AMOUNT	\$37-43	\$45-51	\$53-59

GAS BURNED BETWEEN JAN. 1, 1969 AND DEC. 31, 1969

MILLION CUBIC FEET _____ COST WHOLE AMOUNT \$ _____
61-66 68-74

PERCENT OF SPACE HEATING REQUIREMENTS
WHICH CAN BE MET BY GAS - IF AVAILABLE

_____ %
75-76

PERCENT OF MANUFACTURING PROCESS
REQUIREMENTS WHICH CAN BE MET BY GAS -
IF AVAILABLE

_____ %
77-78

Note: Cards 3 and 4. The \$ figures are checks against the ton or gallon figures and are often more reliable. Card 4 Cols. 75, 76 and 77, 78. If response is "100", keypunch "99".

Fig. A.2 (Contd.)

STACK DATA

5

Check here if you have More than Four Major Stacks ()₁₂

List Stacks with Greatest Output

Height (feet)	13-15	17-19	21-23	25-27
Percent of Total Plant Thermal Output to this Stack	29-30 %	32-33 %	35-36 %	38-39 %
List Type(s) of Fly Ash Control Equipment (see coded list below)	41-42	44-45	47-48	50-51

Collection
Equipment
Code

CODE

ITEM

- 1 - None
 2 - Settling Chamber/Baffles
 3 - Simple Cyclone
 4 - Multiple Cyclone
 5 - Other Inertial Separator (Tubular, Cone, Etc.)

CODE

ITEM

- 6 - Water Sprays in Stack
 7 - Scrubber
 8 - Electrostatic Precipitator
 9 - Other

(DESCRIBE)

REFUSE DATA

6

How many 55-gal Drums of Refuse are Generated per Month? _____
13-19How many 55-gal Drums of Refuse are Burned per Month on the Premises? _____
21-27What are the Principal Types of Refuse Burning Units Used? ()₂₉None

- ()₃₀Coal Boiler ()₃₁Other Boiler ()₃₂55-gal Drum ()₃₃Open Burning
 ()₃₄Single Chamber Incinerator ()₃₅Multiple Chamber Incinerator

What Types of Refuse are Burned?

- ()₃₇Rubbish (dry cartons, paper) ()₃₈Rubbish and Garbage (even mixture)
 ()₃₉Garbage ()₄₀Animal or Human Remains ()₄₁Semi-Solid Industrial Material
 ()₄₂Solid Industrial Material

HOT
WATER
DATA

In WINTER, water is heated by Gas ()

Oil ()

Coal ()₄₄

In SUMMER, water is heated by Gas ()

Oil ()

Coal ()₄₅

(1)

(2)

(3)

Note: For water heated by oil in winter, keypunch a 2 in column 44.

Fig. A.2 (Contd.)

MANUFACTURING PROCESS DATA-A 7

What is the Peak Thermal Load? _____ BTU/HR
13-21
 For which Months is the Average Thermal Load Less than
1/3 this Peak Value?

NONE	J	F	M	A	M	J	J	A	S	O	N	D
23	24	25	26	27	28	29	30	31	32	33	34	35

For which Months is the Average Thermal Load
Greater than 2/3 this Peak Value?

NONE	J	F	M	A	M	J	J	A	S	O	N	D
37	38	39	40	41	42	43	44	45	46	47	48	49

A. What is the Peak Thermal Load in Winter? _____ BTU/HR
51-58

B. What is the Peak Thermal Load in Summer? _____ BTU/HR
61-69

The difference between A and B is due mainly to:
 ()₇₁No Difference ()₇₂Building Heating Requirements
 ()₇₃Seasonal Changes in Process or Refrigeration Requirements

(Leave Blank)

°C/Therm
75-76

77-78 °F

MANUFACTURING PROCESS DATA-B 8

Hours are Approx.

	Mid-8am	8am-4	4pm-Mid
Check which Shifts are Worked on Normal WORKDAYS	13	14	15
Check which Shifts are Worked on HOLIDAYS (July 4, etc.)	17	18	19
Check if there is an OTHER Shift Schedule that occurs Regularly (e.g., half-day, Sat.)	21	22	23

What Percent of the Total Days Fuel is Burned in each Shift? (For each Type of Day, the Sum of the Three Percentages must Total 100%)	WORKDAYS						
	HOLIDAYS						
	OTHER						
	25-26	%	27-28	%	29-30	%	
	32-33	%	34-35	%	36-37	%	
	39-40	%	41-42	%	43-44	%	

On which Days of the Week is each of the Above Work Schedules Followed? (Check Appropriate Boxes)	NONE	M	T	W	T	F	S	S	
	WORKDAYS	46	47	48	49	50	51	52	53
	HOLIDAYS	55	56	57	58	59	60	61	62
OTHER	64	65	66	67	68	69	70	71	

Fig. A.2 (Contd.)

POWER PLANT - UNIT CARD

9

UNIT ^a NUMBER	LIST NUMBER(S) OF STACK(S) COUPLED TO UNIT ^b			MAXIMUM HEAT RATE (MILLION BTU/HR)	ANSWER TO QUESTION A (%)	MAJOR FUEL (SEE CODED LISTS)	
						SUMMER	WINTER
13-14	16	18	20	22-25	27-28	30	32
34-35	37	39	41	43-46	48-49	51	53
55-56	58	60	62	64-67	69-70	72	74

- a. Use actual number of the unit or number them sequentially
b. Stack numbers must correspond to the order of stacks listed on card(s) number 5.
Write one stack number per column.
Question A: What % of the maximum unit output can be met by burning gas, if available?
CODED LIST OF FUELS: 1 - GAS 4 - COAL
2 - DISTILLATE OIL 5 - OTHER
3 - RESIDUAL OIL SPECIFY _____

Fig. A.2 (Contd.)

- d. The percent of space heating requirement that can be met by gas in the base year, PGSH(2,J), is given directly.
e. The percent of the manufacturing process requirement that can be met by gas in the base year, PGP(2,J), is given directly.

Card 5: a. Stack height and percent of emissions allocated to each stack are given directly.

- b. Fly-ash control equipment may be used to calculate pollution conversion factors CFC, CFO, and CFG.

Card 7: a. Peak thermal loads for winter and summer in Btu/hr, PWL(J) and PSL(J), are given directly.

- b. The months in which average loads were less than one-third and greater than two-thirds peak (Q,R,S) are given directly.
c. The threshold temperature, TEMP(J), that may be obtained from the local gas company is added to this card in the box in the lower right-hand side.
d. The reason for the difference, if one exists, between PWL and PSL is given directly.

Cards 6, 7, and 8 are not used in this model. Card 9 is used for data on electrical power generation. However, additional information not provided in these cards is needed. Questions concerning future plans on control devices and fuel usage must be added. Base-year control devices other than fly ash are not included in these cards. These other control devices and future plans for improvements are needed to calculate CFC, CFO, and CFG. In addition, "growth" rates are required. Such rates may be supplied by the

individual firms, but would most likely represent objectives rather than projections. Three alternative approaches to obtaining growth rates are presented below, in the order of preference. Much of the missing data, other than growth-rate data, could be added to the data card set to extend its usefulness.

2.2.1 Growth-rate Estimating Data

1. If historical output or fuel-consumption data are available for each firm, a growth rate could be calculated similar to the growth-rate calculations made in the residential model. Annual reports may be used, but output measured in dollar sales must be adjusted to account for inflation.

2. Regional growth rates for each of the Standard Industrial Classifications related to the study region may be used. Data to make these calculations may be found in the census of manufacturing or the census of transportation. Data may also be available from local planning groups.

3. The last alternative is to use national growth rates for each industrial classification. Census data or trade journals may be used.

2.3 Industrial/Commercial Area Sources

The model presented earlier for area sources requires the following information:

1. The total fuel or energy requirements of industrial and commercial activities in the region, and
2. The share of the market held by each fuel for the base and target years, or
3. The total fuel consumed by type for two years.

In addition, the following is needed:

4. The pollutant content of each fuel in each year studied,
5. The fuel consumed by point sources,
6. The pertinent conversion factors,
7. Estimates of stack heights for use in a dispersion model, and
8. A zoning map.

Although these data requirements are not excessive, they may, nevertheless, be difficult to satisfy. A potential source of the information required is the area fuel distributors. If the fuel distributors collect data

related to the requirements of the model, they would most likely have it in the form of quantities of fuel sold to each customer, rather than in terms of total energy requirements. This means that the second approach would be applied. However, if this information is available for only one year, it could easily be transformed into energy requirements, and the first approach applied. Furthermore, the fuel distributors may have data that provide a measure of their market shares and the projected market shares of their fuel in the future. Of course, the analyst must be judicious about the use of market share "projection," since these often represent objectives for the future rather than projections.

If the base year's energy requirements or fuel-consumption data are not available from the fuel distributors, two alternative approaches to obtain equivalent information are:

1. Fuel-use Survey. This survey would use the same techniques as those used in the point-source survey. A 100% survey need not be conducted. Stochastic sampling techniques should be used to reduce the time and the costs required to obtain the data.

2. Building Count. An alternative to the fuel-use-survey approach is a building count which generates the number of industrial and commercial buildings of a particular size in the region. Such a building count may have already been conducted by groups such as associations of commerce and industry, or the Bureau of Census. If not, its advantages over the survey approach is the ease with which it can be conducted, since no personal contact is required. It is, of course, less accurate, since energy requirements would have to be estimated using size-energy relationships which are technologically based and include temperature and efficiency.

If either of these approaches is required, the level of industrial and commercial activity for each grid could be obtained with practically no additional effort. Therefore, the allocation of the activity using the zoning ordinance is not required.

Stack-height data could also be estimated using these approaches. The data on pollution contents of fuels and conversion factors are estimated in exactly the same manner as they were estimated for the other models.

2.4 Power-generating Sources

Because of the importance of the electric power utilities, the analysis is more detailed. For example, production functions, demand functions, and capacities are specified rather than assumed, as they were with industrial point sources. This added detail, as would be expected, increases the data requirements. However, the monopolistic and regulated characteristics of electric power companies makes the collection of these data practical.

The data requirements can be summarized as follows:

1. Hourly-load-versus-temperature charts for the company, i.e., demand functions.
2. Thermal-input-versus-load graphs for each unit in the study region, i.e., production functions.
3. Capacities and efficiencies for all units in the system.
4. Fuel-use-versus-temperature chart for each unit in the study region.
5. Growth rate of system.
6. Change in efficiencies of existing units in the system.
7. Plans for construction and retirement of units and related data.

All these data can be obtained directly from the electric power company. However, a growth rate of 7% may be used if it is felt the power company's growth rate represents an objective rather than a prediction. Furthermore, a threshold temperature similar to that used in the industrial point-source model may have to be obtained from the local gas utility company to calculate the fuel-use-versus-temperature relationships.

APPENDIX B

A Computerized Historical Climatology Model
for Air-pollution Planning

(J. E. Norco)

1. Program Description

The basic purpose of the climatology code is to determine how frequently user-defined combinations of meteorological variables (met sets) have been observed. In addition, frequencies of various persistence levels of any met set are determined. A persistence level is a time interval or band during which the met set is observed to persist. For example, the input may define four persistence bands:

≤ 2 , 3-6, 7-18, ≥ 19 hr.

The program would search the available inventory of historical weather data (hourly observations) and record how many times each specified met set persisted for each band. The percent of the total number of observations accounted for by each persistence band is also printed. Aggregate frequencies based on the individual observations are computed and ordered. The climatology data display program is coded in the PL/I language for the IBM System 360. (See Section 2 of this appendix.)

1.1 Input

Any standard U.S. Weather Bureau tape may be used as the historical data base; however, two job steps are required to form a preprocessed data tape which the basic climatology program reads and processes:

1. The original tapes contain card images blocked 24 cards per record, coded in BCD. A 15-year tape would take about 35 min to read. To reduce this time and because the program is written to accept fixed-point input numbers, the original tape is processed by a program called CONVERT, which writes a new tape in fixed-point binary. It also extracts only variables 1-16 (see Table B.1), a sufficient assortment for most air-pollution studies.

2. The CONVERT output tape is processed by STABJOB, which computes the Turner stability class number for each hourly observation and adds it to the 16 parameters extracted from the original tape. The STABJOB output tape then constitutes the input for the climatology program PERSIST.

Program input is completely flexible. Once the input tape has been formed, the user may specify any combination of the variables on that tape as a met set and may define the bandwidths and bands for each variable.

The display of persistence levels is optional, and seasonal stratifications are permitted. A program input description, complete with a sample input set, is provided in Section 3 of this appendix.

TABLE B.1. Variable Locations on Tape

Tape No. 079356	
1	Year
2	Month
3	Day
4	Hour
5	Ceiling: hundreds of feet (9999 = unlimited)
6	Rain
7	Snow
	} encoded
8	Sea-level pressure: millibars
9	Dew point: °F
10	Wind direction: encoded
11	Wind speed: mph
12	Station pressure: in. Hg
13	Dry-bulb temperature: °F
14	Wet-bulb temperature: °F
15	Relative humidity: %
16	Cloud cover: 0-9; (" - ") = 10
17	Turner stability: 1-5

Any variable equal to 99999 is unknown.

1.2 Output

Output information is tabulated in this same sequence as it is defined in the input. For each met set, the following information is printed:

1. The number of times the specified set was observed for each specified persistence level, along with the corresponding percentage of the total number of observations associated with that particular met set.
2. The frequency and percent of total for all the hourly observations.
3. In a separate table, the same output as in 2 above, but ordered in descending order of frequency of occurrence. (Sample program output is given in Section 4 of this appendix.)

2. Program Listing

```

PERSIST: PROCEDURE OPTIONS(MAIN);
DECLARE TITLE CHARACTER(80),
TOTAL_HEAD(2) CHARACTER(7) INITIAL('! TOTAL','! HOURS'),
PER_HEAD(2) CHARACTER(7) INITIAL('! % OF ','! TOTAL'),
CARD CHARACTER(80),
FLAG BIT(1),
CHECK_DATE BIT(1),
STARTING_DATE(3) FIXED BINARY(31),
ENDING_DATE(3) FIXED BINARY(31),
SYSIN RECORD,
ROW BINARY FIXED,
VARIABLE_NAME(NUMBER_OF_VARIABLES,2) CHARACTER(8) CONTROLLED,
LOC_OF_VARIABLE(NUMBER_OF_VARIABLES) BINARY FIXED(31)
CONTROLLED,
VARIABLE(NUMBER_OF_VARIABLES) FIXED BINARY(31) CONTROLLED,
TABLE(NUMBER_OF_ROWS,NUMBER_OF_PERSISTENCE_LEVELS,2)
BINARY FIXED(31) CONTROLLED,
(OLD_ROW_NUMBER,ROW_NUMBER) BINARY FIXED,
RECORD(LENGTH_OF_RECORD) BINARY FIXED(31) CONTROLLED,
PRINT_INPUT BIT(1),
CATEGORY_MAX(NUMBER_OF_VARIABLES,MAX_CATEGORIES)
BINARY FIXED(31) CONTROLLED,
CATEGORY_MIN(NUMBER_OF_VARIABLES,MAX_CATEGORIES)
BINARY FIXED(31) CONTROLLED,
COL_TOTAL(NUMBER_OF_PERSISTENCE_LEVELS) BIN FIXED(31)
CONTROLLED,
ROW_TOTAL_HOURS(NUMBER_OF_ROWS) BIN FIXED(31) CONTROLLED,
ROW_TOTAL_PER(NUMBER_OF_ROWS) DECIMAL FLOAT(16) CONTROLLED,
TOTAL_HOURS BINARY FIXED(31),
PERCENT_OF_COL(NUMBER_OF_PERSISTENCE_LEVELS)
DECIMAL FLOAT(16) CONTROLLED,
PERSISTENCE_LEVEL(NUMBER_OF_PERSISTENCE_LEVELS) BIN FIXED(31)
CONTROLLED,
VARIABLE_TO_INCREASE BIN FIXED,
COLUMN_TITLE(2) CHARACTER(LENGTH_OF_COL_TITLE) CONTROLLED,
I_AT_CAT(NUMBER_OF_VARIABLES) BIN FIXED CONTROLLED,
CATEGORY_NAME(NUMBER_OF_VARIABLES,MAX_CATEGORIES) CHARACTER(8)
CONTROLLED,
NUMBER_OF_CATEGORIES(NUMBER_OF_VARIABLES) CONTROLLED;
DECLARE (MAX_ROW,MAX_HOURS) BINARY FIXED(31);
NEXT_CASE:
ON ENDFILE(SYSIN) GO TO ALL_DONE;
READ FILE(SYSIN) INTO (TITLE);
READ FILE(SYSIN) INTO (CARD);
GET STRING(CARD) EDIT (NUMBER_OF_VARIABLES,MAX_CATEGORIES,
PRINT_INPUT,NUMBER_OF_PERSISTENCE_LEVELS,LENGTH_OF_RECORD,
CHECK_DATE,(STARTING_DATE(1),ENDING_DATE(1) DO I=1 TO 3))
(2 F(3),8(1),2 F(3),8(1),6 F(3));
LENGTH_OF_COL_TITLE=13*NUMBER_OF_PERSISTENCE_LEVELS;
ALLOCATE VARIABLE_NAME,LOC_OF_VARIABLE,VARIABLE,RECORD,
CATEGORY_MAX,CATEGORY_MIN,PERSISTENCE_LEVEL,
COLUMN_TITLE,I_AT_CAT,CATEGORY_NAME,NUMBER_OF_CATEGORIES;
READ FILE(SYSIN) INTO (CARD);
COLUMN_TITLE(1)=CARD;
READ FILE(SYSIN) INTO (CARD);
COLUMN_TITLE(2)=CARD;
DO I=1 TO NUMBER_OF_VARIABLES;
READ FILE(SYSIN) INTO (CARD);
GET STRING(CARD) EDIT (LOC_OF_VARIABLE(I),
NUMBER_OF_CATEGORIES(I),(VARIABLE_NAME(I,J) DO J=1 TO 2))
(2 F(2),X(4),2 A(8));
DO J=1 TO NUMBER_OF_CATEGORIES(I);

```



```

        READ FILE(SYSIN) INTO(CARD);
        GET STRING(CARD) EDIT (CATEGORY_NAME(I,J),
            CATEGORY_MIN(I,J),CATEGORY_MAX(I,J))
            (A(8),2 F(8));
    END;
END;
READ FILE(SYSIN) INTO (CARD);
GET STRING(CARD) EDIT ((PERSISTENCE_LEVEL(I) DO I=1 TO
    NUMBER_OF_PERSISTENCE_LEVELS))(10 F(8));
NUMBER_OF_ROWS=1;
DO I=1 TO NUMBER_OF_VARIABLES;
    NUMBER_OF_ROWS=NUMBER_OF_ROWS*NUMBER_OF_CATEGORIES(I);
END;
    ALLOCATE TABLE,COL_TOTAL,ROW_TOTAL_HOURS,PERCENT_OF_COL,
        ROW_TOTAL_PER;
    PUT DATA(NUMBER_OF_VARIABLES,MAX_CATEGORIES,LOC_OF_VARIABLE,
        NUMBER_OF_CATEGORIES,VARIABLE_NAME,CATEGORY_NAME,
        CATEGORY_MIN,CATEGORY_MAX);
    PUT DATA(CHECK_DATE,STARTING_DATE,ENDING_DATE);
    ON ENDFILE(TAPE)
    BEGIN;
        FLAG='0'B;
        ROW_NUMBER=0;
        GO TO SET_PERSISTENCE;
    END;
    TABLE=0;
    ROW_TOTAL_HOURS=0;
        LENGTH_OF_PERSISTENCE=0;
    OLD_ROW_NUMBER=0;
    NUM_COLS_USED=9*NUMBER_OF_VARIABLES+
        13*NUMBER_OF_PERSISTENCE_LEVELS+14;
    NUM_COLS_SKIPPED=(133-NUM_COLS_USED)/2 ;
    FLAG='1'B;
NEXT_RECORD:
    READ FILE(TAPE) INTO (RECORD);
    IF CHECK_DATE THEN
    DO;
        IF RECORD(1)>STARTING_DATE(1)&RECORD(1)<ENDING_DATE(1)
            THEN GO TO GOOD_DATE;
        IF RECORD(1)<STARTING_DATE(1) THEN GO TO NEXT_RECORD;
        IF RECORD(1)>ENDING_DATE(1) THEN
        DO;
            ROW_NUMBER=0;
            FLAG='0'B;
            GO TO SET_PERSISTENCE;
        END;
        IF RECORD(1)=STARTING_DATE(1) THEN
        DO;
            IF RECORD(2)>STARTING_DATE(2) THEN GO TO GOOD_DATE;
            IF RECORD(2)=STARTING_DATE(2)&RECORD(3)>=STARTING_DATE(3)
                THEN GO TO GOOD_DATE;
            GO TO NEXT_RECORD;
        END;
        IF RECORD(2)<ENDING_DATE(2) THEN GO TO GOOD_DATE;
        IF RECORD(2)=ENDING_DATE(2)&RECORD(3)<=ENDING_DATE(3)
            THEN GO TO GOOD_DATE;
        ROW_NUMBER=0;
        FLAG='0'B;
        GO TO SET_PERSISTENCE;
    END;
GOOD_DATE:
    DO I=1 TO NUMBER_OF_VARIABLES;
        VARIABLE(I)=RECORD(LOC_OF_VARIABLE(I));

```

```

END;
IF PRINT_INPUT THEN
  PUT EDIT((VARIABLE(I) DO I=1 TO NUMBER_OF_VARIABLES))
    (SKIP(1),(NUMBER_OF_VARIABLES) F(6));
ROW_NUMBER=0;
DO I_AT_VAR=1 TO NUMBER_OF_VARIABLES;
  DO
    J=1 TO NUMBER_OF_CATEGORIES(I_AT_VAR);
    IF CATEGORY_MAX(I_AT_VAR,J)>=CATEGORY_MIN(I_AT_VAR,J) THEN
      DO;
        IF VARIABLE(I_AT_VAR)<=CATEGORY_MAX(I_AT_VAR,J)
          &VARIABLE(I_AT_VAR)>=CATEGORY_MIN(I_AT_VAR,J)
          THEN GO TO FOUND_CATEGORY;
      END;
    ELSE
      IF VARIABLE(I_AT_VAR)<=CATEGORY_MAX(I_AT_VAR,J)
        |VARIABLE(I_AT_VAR)>=CATEGORY_MIN(I_AT_VAR,J)
        THEN GO TO FOUND_CATEGORY;
    END;
  ROW_NUMBER=0;
  GO TO SET_PERSISTENCE;
FOUND_CATEGORY:
  M=1;
  IF I_AT_VAR<NUMBER_OF_VARIABLES THEN
    DO;
      DO I=I_AT_VAR+1 TO NUMBER_OF_VARIABLES;
        M=M*NUMBER_OF_CATEGORIES(I);
      END;
      ROW_NUMBER=ROW_NUMBER+(J-1)*M;
    END;
  ELSE ROW_NUMBER=ROW_NUMBER+J;
END;
SET_PERSISTENCE:
  IF ROW_NUMBER<=OLD_ROW_NUMBER THEN IF OLD_ROW_NUMBER<=0 THEN
    DO;
      DO I=NUMBER_OF_PERSISTENCE_LEVELS TO 1 BY -1;
        IF LENGTH_OF_PERSISTENCE>=PERSISTENCE_LEVEL(I)
          THEN GO TO FOUND_LEVEL;
      END;
      PUT EDIT('WHY ARE YOU HERE')(A);
    FOUND_LEVEL:
      ROW_TOTAL_HOURS(OLD_ROW_NUMBER)=ROW_TOTAL_HOURS(OLD_ROW_NUMBER)
        +LENGTH_OF_PERSISTENCE;
      TABLE(OLD_ROW_NUMBER,I,1)=TABLE(OLD_ROW_NUMBER,I,1)+1;
      TABLE(OLD_ROW_NUMBER,I,2)=TABLE(OLD_ROW_NUMBER,I,2)+
        LENGTH_OF_PERSISTENCE;
      LENGTH_OF_PERSISTENCE=0;
    END;
    IF OLD_ROW_NUMBER=0 THEN LENGTH_OF_PERSISTENCE=0;
    OLD_ROW_NUMBER=ROW_NUMBER;
    LENGTH_OF_PERSISTENCE=LENGTH_OF_PERSISTENCE+1;
    IF FLAG THEN GO TO NEXT_RECORD;
    I_AT_CAT =1;
    I_AT_CAT (NUMBER_OF_VARIABLES)=0;
    VARIABLE_TO_INCREASE=NUMBER_OF_VARIABLES;
    NUMBER_OF_LINES_ON_THIS_PAGE=52;
    COL_TOTAL=0;
    DO I=1 TO NUMBER_OF_PERSISTENCE_LEVELS;
      DO J=1 TO NUMBER_OF_ROWS;
        COL_TOTAL(I)=COL_TOTAL(I)+TABLE(J,I,1);
      END;
    END;
    TOTAL_HOURS=0;
    DO ROW=1 TO NUMBER_OF_ROWS;

```

```

TOTAL_HOURS=TOTAL_HOURS+ROW_TOTAL_HOURS(ROW);
END;
DO ROW=1 TO NUMBER_OF_ROWS;
  NUMBER_OF_LINES_ON_THIS_PAGE=NUMBER_OF_LINES_ON_THIS_PAGE+1;
  IF NUMBER_OF_LINES_ON_THIS_PAGE<53 THEN GO TO FIND_CATEGORIES;
  IF NUMBER_OF_VARIABLES>1 THEN
    NUMBER_OF_LINES_ON_THIS_PAGE=
      NUMBER_OF_CATEGORIES(NUMBER_OF_VARIABLES);
  ELSE NUMBER_OF_LINES_ON_THIS_PAGE=1;
  PUT EDIT(TITLE) (PAGE,X(26),A);
  PUT EDIT((' ' DO I=1 TO NUM_COLS_USED))
    (SKIP(2),X(NUM_COLS_SKIPPED),133 A(1));
  PUT EDIT(((VARIABLE_NAME(I,J),' ' DO I=1 TO NUMBER_OF_VARIABLES)
    ,COLUMN_TITLE(J),TOTAL_HEAD(J),PER_HEAD(J)
      DO J=1 TO 2))(SKIP(1),
    X(NUM_COLS_SKIPPED),(NUMBER_OF_VARIABLES)(A(8),A(1)),
    A,2 A(7));
  PUT EDIT((' ' DO I=1 TO NUM_COLS_USED))
    (SKIP(1),X(NUM_COLS_SKIPPED),133 A(1));
  PUT EDIT(' ')(SKIP(1),A);
FIND_CATEGORIES:
  I_AT_CAT (VARIABLE_TO_INCREASE)=
    I_AT_CAT (VARIABLE_TO_INCREASE)+1;
  IF I_AT_CAT (VARIABLE_TO_INCREASE)<=NUMBER_OF_CATEGORIES(
    VARIABLE_TO_INCREASE) THEN GO TO PRINT_ROW;
  IF VARIABLE_TO_INCREASE=NUMBER_OF_VARIABLES
    &NUMBER_OF_LINES_ON_THIS_PAGE=NUMBER_OF_CATEGORIES
    (NUMBER_OF_VARIABLES) THEN
    DO;
      PUT EDIT(' ')(SKIP(1),A);
      NUMBER_OF_LINES_ON_THIS_PAGE=NUMBER_OF_LINES_ON_THIS_PAGE+1;
    END;
  I_AT_CAT(VARIABLE_TO_INCREASE)=1;
  VARIABLE_TO_INCREASE=VARIABLE_TO_INCREASE-1;
  IF VARIABLE_TO_INCREASE=0 THEN GO TO FIND_CATEGORIES;
  PUT EDIT('WHY ARE YOU HERE')(PAGE ,A);
  GO TO STOP;
PRINT_ROW:
  VARIABLE_TO_INCREASE=NUMBER_OF_VARIABLES;
  DO I=1 TO NUMBER_OF_PERSISTENCE_LEVELS;
    PERCENT_OF_COL(I)=TABLE(ROW,I,2);
    IF COL_TOTAL(I)>0 THEN PERCENT_OF_COL(I)=
      PERCENT_OF_COL(I)/TOTAL_HOURS*100.0000;
    ELSE PERCENT_OF_COL(I)=0.000 ;
  END;
  ROW_TOTAL_PER(ROW)=ROW_TOTAL_HOURS(ROW);
  IF ROW_TOTAL_PER(ROW)>0 THEN ROW_TOTAL_PER(ROW)=ROW_TOTAL_PER
    (ROW)/TOTAL_HOURS*100.0000;
  PUT EDIT((CATEGORY_NAME(I,I_AT_CAT(I)), ' ' DO I=1 TO
    NUMBER_OF_VARIABLES),(TABLE(ROW,I,1) ,PERCENT_OF_COL(I)
    DO I=1 TO NUMBER_OF_PERSISTENCE_LEVELS), ' ',
    ROW_TOTAL_HOURS(ROW),ROW_TOTAL_PER(ROW))
    (SKIP(1),X(NUM_COLS_SKIPPED),
    (NUMBER_OF_VARIABLES) (A(8),A(1)),
    (NUMBER_OF_PERSISTENCE_LEVELS) (P 'ZZZZZZ',P 'ZZZV.ZZZ'
    ),A(1),P 'ZZZZZZ',P 'ZZZV.ZZZ');
  XTEMP=ROW_TOTAL_HOURS(ROW);
  XTEMP=XTEMP/TOTAL_HOURS;
  PUT FILE(SYSPNCH)EDIT(XTEMP,',')(F(7,6),A(1));
END;
PUT EDIT((COL_TOTAL(I) DO I=1 TO NUMBER_OF_PERSISTENCE_LEVELS),
  TOTAL_HOURS)(SKIP(2),X(NUM_COLS_SKIPPED+
  9*NUMBER_OF_VARIABLES),(NUMBER_OF_PERSISTENCE_LEVELS)

```

```

      (P 'ZZZZZZ',X(7)),P 'ZZZZZZ');
NUMBER_OF_LINES_ON_THIS_PAGE=40;
DO ROW=1 TO NUMBER_OF_ROWS;
  NUMBER_OF_LINES_ON_THIS_PAGE=NUMBER_OF_LINES_ON_THIS_PAGE+1;
  IF NUMBER_OF_LINES_ON_THIS_PAGE<41 THEN GO TO FIND_NEXT_ROW;
  NUMBER_OF_LINES_ON_THIS_PAGE=1;
  PUT EDIT(TITLE)(PAGE,X(26),A);
  PUT EDIT((' ' DO I=1 TO NUM_COLS_USED))
    (SKIP(2),X(NUM_COLS_SKIPPED),133 A(1));
  PUT EDIT(((VARIABLE_NAME(I,J),'I' DO I=1 TO NUMBER_OF_VARIABLES)
    ,COLUMN_TITLE(J),TOTAL_HEAD(J),PER_HEAD(J)
      DO J=1 TO 2))(SKIP(1),
    X(NUM_COLS_SKIPPED),(NUMBER_OF_VARIABLES)(A(8),A(1)),
    A,2 A(7));
  PUT EDIT((' ' DO I=1 TO NUM_COLS_USED))
    (SKIP(1),X(NUM_COLS_SKIPPED),133 A(1));
  PUT EDIT(' ')(SKIP(1),A);
FIND_NEXT_ROW:
  MAX_ROW=0;MAX_HOURS=0;
  DO I=1 TO NUMBER_OF_ROWS;
    IF ROW_TOTAL_HOURS(I)>MAX_HOURS THEN
      DO;
        MAX_ROW=I;
        MAX_HOURS=ROW_TOTAL_HOURS(I);
      END;
  END;
  IF MAX_ROW=0 THEN GO TO STOP;
  ROW_TOTAL_HOURS(MAX_ROW)=0;
  L=MAX_ROW-1;
  DO I=1 TO NUMBER_OF_VARIABLES;
    K=1;
    DO J=I+1 TO NUMBER_OF_VARIABLES;
      K=K*NUMBER_OF_CATEGORIES(J);
    END;
    I_AT_CAT(I)=L/K+1;
    I=L-(I_AT_CAT(I)-1)*K;
  END;
  I=NUMBER_OF_LINES_ON_THIS_PAGE/5;
  I=NUMBER_OF_LINES_ON_THIS_PAGE-I*5;
  IF I=1 THEN PUT EDIT(' ')(SKIP(1),A);
  DO I=1 TO NUMBER_OF_PERSISTENCE_LEVELS;
    PERCENT_OF_COL(I)=TABLE(MAX_ROW,I,2);
    IF COL_TOTAL(I)>0 THEN PERCENT_OF_COL(I)=
      PERCENT_OF_COL(I)/TOTAL_HOURS*100.0000;
    ELSE PERCENT_OF_COL(I)=0.000;
  END;
  PUT EDIT((CATEGORY_NAME(I,I_AT_CAT(I)), ' ' DO I=1 TO
    NUMBER_OF_VARIABLES),(TABLE(MAX_ROW,I,1),
    PERCENT_OF_COL(I) DO I=1 TO
    NUMBER_OF_PERSISTENCE_LEVELS),' ',MAX_HOURS,
    ROW_TOTAL_PER(MAX_ROW))
    (SKIP(1),X(NUM_COLS_SKIPPED),
    (NUMBER_OF_VARIABLES) (A(8),A(1)),
    (NUMBER_OF_PERSISTENCE_LEVELS)(P 'ZZZZZZ',P 'ZZZV.ZZZ')
    ,A(1),P 'ZZZZZZ',P 'ZZZV.ZZZ');
END;
STOP:
  FREE VARIABLE_NAME,LOC_OF_VARIABLE,VARIABLE,RECORD,
    CATEGORY_MAX,CATEGORY_MIN,PERSISTENCE_LEVEL,
    COLUMN_TITLE,I_AT_CAT,CATEGORY_NAME,NUMBER_OF_CATEGORIES;
  FREE TABLE,COL_TOTAL,ROW_TOTAL_HOURS,PERCENT_OF_COL,
    ROW_TOTAL_PER;
  CLOSE FILE(TAPE);
  GO TO NEXT_CASE;
ALL_DONE:
END PERSIST;

```

3. Input Description

3.1 Input Information Required

<u>Card Type</u>	<u>Columns</u>	<u>Contents</u>	<u>Description</u>
1	1-80	TITLE	Title, which should be centered in the 80-column field.
2	1-3	NUMBER_OF_VARIABLES	Number of independent variables.
	4-6	MAX_CATEGORIES	The maximum number of categories to be used for any of the independent variables.
	7	PRINT_INPUT	If the input variables are to be printed, then 1; otherwise 0. (NOTE: A blank may <u>not</u> be substituted for 0.)
	8-10	NUMBER_OF_PERSISTENCE_LEVELS	Number of persistence levels to be printed.
	11-13	LENGTH_OF_RECORD	Number of variables on input data tape.
	14	CHECK_DATE	If CHECK_DATE = 0, then program analyzes all data on input data tape. If CHECK_DATE = 1, then only the data from starting date to ending date are analyzed. In this case, it is assumed that the first variable on input data tape is the YEAR, the second variable is the MONTH, and the third variable is the DAY.
	15-17	STARTING_DATE(1)	Starting year.
	18-20	ENDING_DATE(1)	Ending year.
	21-23	STARTING_DATE(2)	Starting month of starting year.
	24-26	ENDING_DATE(2)	Ending month of ending year.
	27-29	STARTING_DATE(3)	Starting day of starting month of starting year.
	30-32	ENDING_DATE(3)	Ending day of, ending month of ending year.
3	1-13* (NUMBER_OF_PERSISTENCE_LEVELS)	COLUMN_TITLE(1)	First row of headings for columns with persistence levels. This should be centered in appropriate columns.
4	1-13* (NUMBER_OF_PERSISTENCE_LEVELS)	COLUMN_TITLE(2)	Second row of headings for columns with persistence levels. This should be centered in appropriate columns.

There must be NUMBER_OF_VARIABLES cards of type 5. Each card of type 5 must be immediately followed by NUMBER_OF_CATEGORIES(I) cards of type 6, where I is the variable being considered.

<u>Card Type</u>	<u>Columns</u>	<u>Contents</u>	<u>Description</u>
5	1-2	LOC_OF_VARIABLE(I)	The location of the Ith variable in a record on the input data tape.
	3-4	NUMBER_OF_CATEGORIES(I)	Number of categories for the Ith variables.
	5-8	Not used	
	9-16	VARIABLE_NAME(I,1)	First part of name for Ith variable.
	17-24	VARIABLE_NAME(I,2)	Second part of name for Ith variable.
6	1-8	CATEGORY_NAME(I,J)	The name for the Jth category Ith variable.
	9-16	CATEGORY_MIN(I,J)	The minimum value for the Jth category of the Ith variable.
	17-24	CATEGORY_MAX(I,J)	The maximum value for the Jth category of the Ith variable.

NOTE: If $CATEGORY_MIN(I,J) \leq CATEGORY_MAX(I,J)$ then the Ith variable falls in its Jth category if $CATEGORY_MIN(I,J) \leq VARIABLE(I) \leq CATEGORY_MAX(I,J)$.

If $CATEGORY_MIN(I,J) > CATEGORY_MAX(I,J)$ then the Ith variable falls in its Jth category if $VARIABLE(I) \leq CATEGORY_MAX(I,J)$ or if $VARIABLE(I) \geq CATEGORY_MIN(I,J)$.

7	1-8	PERSISTENCE_LEVEL(1)
	9-16	PERSISTENCE_LEVEL(2)
		PERSISTENCE_LEVEL (NUMBER_OF_PERSISTENCE_LEVELS)

NOTE: A particular combination of variables will fall in the Ith persistence level if that combination of variables stays the same for $\geq PERSISTENCE_LEVEL(I)$ and $< PERSISTENCE_LEVEL(I+1)$ consecutive readings.

Input Data Tape: All variables on the input data tape are assumed to be full-word fixed-point numbers.

OUTPUT INFORMATION:

1. If $PRINT_INPUT = 1$, then a listing of the input variables is obtained.
2. All input variable values for which no category was found are listed.
3. A table as described in the description of the problem is presented. For each persistence level and for each set of categories, a number is printed specifying how many times this persistence level was reached for this set of categories. In addition, a number is printed giving the percentage of the time this set of categories caused this persistence level to be reached. A number is also printed out which specifies how many times this set of categories occurred. At the end of the table, the total number of times each persistence level occurred is printed.

3.2 Sample Input

COST CODE _____

PROGRAM										PROBLEM										ORIGINATOR										DATE										PAGE										OF																													
1										2										3										4										5										6										7										8									
1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0																				
																				TEST CASE																																																											
4 50										5 171 49 50 7 6 1 30																																																																					
										PERSISTENCE										LEVEL (HOURS)																																																											
1										%										2 - 12 %										1,3 - 2,4 %										2,5 - 3,6 %										> 3,6 %																													
2 4										SEASON																																																																					
DEC - FEB										1 2										2																																																											
MAR - MAY										3										5																																																											
JUN - AUG										6										8																																																											
SEP - NOV										9										11																																																											
1,3 4										TEMP										(F)																																																											
< 1,5										- 9,9 9										1,4																																																											
1,5 - 3,5										1,5										3,5																																																											
3,6 - 5,5										3,6										5,5																																																											
> 5,5										5,6										9,9 9,9																																																											
1 0 5										WIND										DIR																																																											
CALM										0										0																																																											
NORTH										1 1										2 2																																																											
EAST										3 2										4 4																																																											
SOUTH										5 4										6 6																																																											
WEST										7 6										8 8																																																											
1 4										WIND SPD										(MPH)																																																											
0 - 4										0										4																																																											
5 - 10										5										10																																																											
11 - 20										11										20																																																											
> 20										21										99 99																																																											

AMD-18 (7-66)

1

2

1 3

2 5

3 7

4. Sample Output

4.1 Basic Sample Output

SEASON	WIND DIR.	WIND SPC (MPH)	STAB CLASS	PERSISTENCE LEVEL (HOURS)								TOTAL HOURS	% OF TOTAL
				1-12	%	13-24	%	25-48	%	49-72	%		
DEC-MAR	NORTH	0-10	1-3	360	.432							588	.432
DEC-MAR	NORTH	0-10	4	1486	2.247	16	.200	1	.022			3356	2.469
DEC-MAR	NORTH	0-10	5	829	1.371	1	.009					1876	1.380
DEC-MAR	NORTH	11-20	1-3	32	.027							37	.027
DEC-MAR	NORTH	11-20	4	1696	3.534	56	.655	9	.194	1	.241	6015	4.426
DEC-MAR	NORTH	11-20	5	248	.232							316	.232
DEC-MAR	NORTH	>20	1-3										
DEC-MAR	NORTH	>20	4	331	.601	3	.045	1	.018			904	.665
DEC-MAR	NORTH	>20	5										
DEC-MAR	EAST	0-10	1-3	207	.285							388	.285
DEC-MAR	EAST	0-10	4	1130	1.832	18	.200					2763	2.033
DEC-MAR	EAST	0-10	5	481	.865	5	.050					1245	.916
DEC-MAR	EAST	11-20	1-3	30	.030							42	.030
DEC-MAR	EAST	11-20	4	723	1.396	17	.212	1	.023			2219	1.633
DEC-MAR	EAST	11-20	5	45	.041							57	.041
DEC-MAR	EAST	>20	1-3										
DEC-MAR	EAST	>20	4	58	.069	1	.011					111	.081
DEC-MAR	EAST	>20	5										
DEC-MAR	SOUTH	0-10	1-3	273	.331							451	.331
DEC-MAR	SOUTH	0-10	4	1525	2.333	4	.044	1	.033			3276	2.411
DEC-MAR	SOUTH	0-10	5	896	1.614	5	.050					2263	1.665
DEC-MAR	SOUTH	11-20	1-3	24	.021							29	.021
DEC-MAR	SOUTH	11-20	4	1395	3.160	55	.638	3	.069			5257	3.868
DEC-MAR	SOUTH	11-20	5	234	.236							322	.236
DEC-MAR	SOUTH	>20	1-3										
DEC-MAR	SOUTH	>20	4	224	.350							476	.350
DEC-MAR	SOUTH	>20	5										
DEC-MAR	WEST	0-10	1-3	358	.451							613	.451
DEC-MAR	WEST	0-10	4	1292	1.764	2	.020					2426	1.785
DEC-MAR	WEST	0-10	5	952	1.482	2	.023					2047	1.506
DEC-MAR	WEST	11-20	1-3	33	.030							42	.030
DEC-MAR	WEST	11-20	4	1763	3.673	47	.510	1	.022	1	.038	5768	4.245
DEC-MAR	WEST	11-20	5	273	.262							357	.262
DEC-MAR	WEST	>20	1-3										
DEC-MAR	WEST	>20	4	427	.750	8	.085	1	.018			1161	.854
DEC-MAR	WEST	>20	5										
APR-MAY	NORTH	0-10	1-3	388	.462							629	.462
APR-MAY	NORTH	0-10	4	725	.942	4	.043					1340	.986

4.2 Sample Output-- Ordered Frequencies

SEASON	WIND DIR.	WIND SPD (MPH)	STAB CLASS	PERSISTENCE LEVEL(HOURS)								TOTAL HOURS	% OF TOTAL
				1-12	%	13-24	%	25-48	%	49-72	%	>72	%
DEC-MAR	NORTH	11-20	4	1696	3.534	56	.655	9	.194	1	.041	6015	4.426
DEC-MAR	WEST	11-20	4	1765	3.673	47	.510	1	.022	1	.038	5768	4.245
DEC-MAR	SOUTH	11-20	4	1395	3.160	55	.638	3	.069			5257	3.868
SEP-NOV	SOUTH	0-10	5	1249	2.857	38	.386					4407	3.243
SEP-NOV	SOUTH	11-20	4	1222	2.656	38	.455	2	.039			4283	3.152
JUN-ALG	SOUTH	0-10	5	1389	3.074							4177	3.074
SEP-NOV	NORTH	11-20	4	1134	2.172	29	.348	2	.038			3478	2.559
DEC-MAR	NORTH	0-10	4	1486	2.247	16	.200	1	.022			3356	2.469
DEC-MAR	SOUTH	0-10	4	1525	2.333	4	.044	1	.033			3276	2.411
SEP-NOV	WEST	11-20	4	1076	1.993	8	.103	3	.064			2936	2.160
JUN-ALG	NORTH	0-10	5	1111	2.066							2808	2.066
SEP-NOV	SOUTH	0-10	4	1417	1.945	8	.091					2767	2.036
DEC-MAR	EAST	0-10	4	1130	1.832	18	.200					2763	2.033
JUN-AUG	EAST	0-10	5	993	1.940							2637	1.940
JUN-AUG	SOUTH	0-10	4	1505	1.861							2529	1.861
DEC-MAR	WEST	0-10	4	1292	1.764	2	.020					2426	1.785
APR-MAY	NORTH	11-20	4	803	1.457	23	.280	1	.030			2402	1.767
APR-MAY	SOUTH	11-20	4	790	1.547	18	.209					2386	1.756
SEP-NOV	NORTH	0-10	5	912	1.723	3	.029					2382	1.753
JUN-AUG	SOUTH	11-20	4	1052	1.652	6	.067					2337	1.719
DEC-MAR	SOUTH	0-10	5	896	1.614	5	.050					2263	1.665
DEC-MAR	EAST	11-20	4	733	1.396	17	.212	1	.023			2219	1.633
JUN-ALG	EAST	0-10	1-3	1047	1.623							2206	1.623
SEP-NOV	NORTH	0-10	4	1033	1.532	7	.072					2181	1.605
JUN-ALG	NORTH	0-10	4	1135	1.474	8	.096	1	.018			2159	1.588
JUN-AUG	SOUTH	0-10	1-3	1117	1.504	1	.009					2057	1.513
DEC-MAR	WEST	0-10	5	952	1.482	2	.023					2047	1.506
JUN-ALG	NORTH	11-20	4	817	1.287	10	.113					1903	1.400
DEC-MAR	NORTH	0-10	5	829	1.371	1	.009					1876	1.380
APR-MAY	WEST	11-20	4	699	1.171	12	.144	1	.024			1821	1.340
SEP-NOV	EAST	0-10	5	661	1.285	5	.050					1815	1.335
JUN-AUG	NORTH	0-10	1-3	1064	1.305							1774	1.305
JUN-AUG	EAST	0-10	4	1043	1.283	2	.022					1774	1.305
SEP-NOV	WEST	0-10	5	812	1.210	1	.010					1659	1.220
JUN-ALG	WEST	11-20	4	750	1.128	2	.019					1560	1.148
APR-MAY	EAST	0-10	4	785	1.111	2	.019					1536	1.130
SEP-NOV	EAST	0-10	4	741	1.035	3	.032	1	.019			1478	1.087
APR-MAY	SOUTH	0-10	5	549	1.036							1409	1.036
JUN-AUG	WEST	0-10	1-3	831	1.031							1402	1.031
JUN-ALG	WEST	0-10	5	740	1.003							1363	1.003

APPENDIX C

An Atmospheric Dispersion Model for Long-range
Air Resource Management Planning

(J. E. Norco)

1. Introduction

For wind speeds greater than or equal to 4 mph, a model based on a steady-state Gaussian plume has been used to compute pollutant concentrations. In a Cartesian-coordinate system with the z-axis vertical and the horizontal axes rotated so that the x-axis coincides with the downwind direction, the basic kernel describing the concentration x at a receptor point x_r, y_r, z_r , due to a steady emission from the point $x = 0, y = 0, z = H$, in an infinite medium is

$$X(x, y, z/H) = \frac{Q_s}{2\pi U \sigma_y \sigma_z} \exp \left[-0.5 \left\{ \left(\frac{y_r}{\sigma_y} \right)^2 + \left(\frac{z_r - H}{\sigma_z} \right)^2 \right\} \right], \quad (51)$$

where

Q_s = pollutant emission rate ($\mu\text{g}/\text{sec}$),

U = mean wind speed (meters/sec),

σ_y = crosswind dispersion coefficient (meters), a function of downwind distance, x^1 ,

σ_z = vertical dispersion coefficient (meters), a function of downwind distance, x^2 ,

y_r = crosswind distance (meters),

z_r = height of receptor (meters),

H = effective height of emission (meters),

and

x = pollutant concentration ($\mu\text{g}/\text{m}^3$).

The dispersion coefficients, σ_y and σ_z , are functions of the downwind distance, x , and are parameterized according to six classes of atmospheric stability (see Figs. C.1 and C.2). The dispersion coefficients shown in Figs. C.1 and C.2 are based on a sampling or averaging time of about 10 min. The smallest time increment of interest in determining expected isopleths is 1 hr. Thus, for use in Eq. 51, the values of σ_y and σ_z in Figs. C.1 and C.2 have been multiplied by the factor $(60 \text{ min}/10 \text{ min})^{0.2} = 1.43$ (Cramer et al., 1964).

Fig. C.1. Horizontal Dispersion Coefficient as a Function of Downwind Distance from the Source (Turner, 1970). ANL Neg. No. 149-3546.

Fig. C.2. Vertical Dispersion Coefficient as a Function of Downwind Distance from the Source (Turner, 1970). ANL Neg. No. 149-3545.

The units of X are $\mu\text{g}/\text{m}^3$. To convert $\mu\text{g}/\text{m}^3$ of SO_2 to parts per million (ppm) at standard temperature (32°F) and pressure (1 atm), divide by 2854. A further correction for the actual temperature is not warranted, considering the uncertainties inherent in the assumed form of the dispersion equation and in the experimentally obtained values of σ_y and σ_z .

Fig. C.3. Reflection at the Ground as Described Mathematically by the Introduction of an Image Source

2. Ground-level Reflection

The assumption that the pollutant is not absorbed when it makes contact with the ground or with buildings can be approximated by a model based on perfect reflection at the ground. In Fig. C.3, two infinite medium sources (Fig. C.1) are superimposed: the actual source at effective height H , and an image source H meters below the reflecting ground plane.

3. Mixing-height Assumption

A stable layer existing at height H_m above an unstable or neutral zone inhibits vertical diffusion and acts as a lid. This phenomenon can be approximated by assuming the existence of a reflecting plane at height H_m , so that in a manner analogous to reflection at ground level, an image source is introduced above the lid plane at height $2H_m - H$ (see Fig. C.4).

Fig. C.4. Reflection at a Stable Layer Represented Mathematically by a Single Image Source L_1 above the Lid

The problem is now complicated by the existence of two reflecting planes, ground and lid. As anyone who has stood between two mirrors knows, the result is describable by introducing multiple (infinite) pairs of reflections at increasing distances from the true source. Figure C.5 shows two pairs of image sources. Close to the source, the images (G_2 and L_2) are insignificant. At greater distances downwind, σ_z increases (see Fig. C.2) and the second set of images becomes important. For example, when $2.15 \sigma_z = 2H_m + H$ in Fig. C.5, the contribution at ground from the image source L_2 is 10% of the concentration on the centerline of the plume.

Fig. C.5

Multiple Reflections between a Stable Layer and Ground Represented Mathematically by Two Sets of Image Sources. The image G_1 is reflected above the lid at L_2 . The image L_1 is reflected below ground at G_2 . ANL Neg. No. 113-2859 Rev. 2.

height above ground of the image L_3 , which is the reflection of G_2 (see Fig. C.5) above the lid.

Figure C.6 shows the approach to the asymptotic distribution of Eq. 52. Equations 51 and 52 have been normalized to remove all dependence on σ_y , U , or Q . The transition from three pairs of images to the uniform distribution (Eq. 52) occurs at $x = 9$ km in Fig. C.6. The jump in concentrations due to the change of algorithms has been emphasized by choosing an example in which plume rise is inhibited by a lid at altitude $H_s = H_m$.

Fig. C.6

Approach to a Uniform Distribution in the Vertical. $H_m = H = 150$ meters. Stability Class D.

The mathematical representation of the concentration of pollutants trapped between two reflecting planes is therefore represented by pairs of images which become important with increasing downwind distance. Eventually, the vertical distribution of pollutants is approximately uniform and the following modified version of Eq. 51 can be used:

$$X(x,y) = \frac{Q_s}{\sqrt{2\pi}\sigma_y U H_m} e^{-0.5(y/\sigma_y)^2}, \quad (52)$$

where H_m = height of mixing layer (meters), and other parameters are as defined following Eq. 51.

The transition from multiple images (Eq. 51 and Fig. C.5) to the uniform distribution can be made smoothly after three pairs of image sources have been introduced and at a downwind distance x_u defined by

$$2.15 \sigma_z(x_u) = 4H_m - H. \quad (53)$$

The right-hand side of Eq. 53 is the

ACKNOWLEDGMENTS

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