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GROWTH EFFECTS OF MAJOR LAND USE PROJECTS: VOLUME III - SUMMARY

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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GROWTH EFFECTS OF MAJOR LAND USE PROJECTS: VOLUME III - SUMMARY

by

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STAFFING

Mr. Frank Benesh was the project manager of this study at Walden Research. Dr. Ralph D'Agostino, contributed to the overall study design and analysis. Mr. Peter Guldberg conducted much of the causal analysis, calibration, and cross-validation of the land use model. Mr. Kenneth Wiltsee contributed the chapters explaining the motor vehicle emissions calculations and Mr. Mahesh Shah assisted in the data collection. The data collection was coordinated by Mrs. Allison B. Goodsell and the manuscript was prepared under the direction of Ms. Gail Kelleher.

Metcalf and Eddy of Boston were subcontractors to Walden Research, assisting in model specification, sample selection, and data collection. Mr. Richard Ball, Mrs. Elizabeth Levin, Mr. Stephen Koop, Mrs. Nancy Lundgren, and Mr. Gerald Takano contributed to Metcalf and Eddy's effort. Mr. Gilbert Nelson conducted much of the development of the traffic model.

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I. INTRODUCTION, ORGANIZATION OF REPORT, AND SUMMARY

A. INTRODUCTION

This report documents the results of a study of the Growth Effects of Major Land Use Projects (GEMLUP). The principal objectives of the GEMLUP study were to formulate a methodology to predict air pollutant emissions from:

- Two types of major land use developments: large concentrations of employment such as office or industrial parks, and large residential developments,
- Land development that is induced by the two types of major land use development projects,
- Motor vehicular traffic associated with both the major project and induced development.

GEMLUP relates to a number of EPA programs, including air quality maintenance plan (AQMP) development [1], environmental impact statement (EIS) review [2], the indefinitely suspended portions of indirect source review [3], and the prevention of significant air quality deterioration, or nondegradation [4]. Explicit or implicit in these programs in an evaluation of air quality impacts of land use plans or project developments. GEMLUP is designed to formulate and test a method of evaluating land use impacts at the project scale, and, in the process, develop a set of land use based emission factors potentially useful at the regional scale.

The study was divided into six phases:

Phase 1 - Specification of a preliminary model and generation of a list of data requirements,

Phase 2 - Data collection,

Phase 3 - Causal analysis of the land use model using path analysis,

Phase 4 - Development of predictive equations for the land use model and development of a traffic model,

Phase 5 - Development of indices of fuel consumption,

Phase 6 - Translation of fuel consumption indices into land use based emission factors.

The first three phases of the study (i.e., model specification, sample selection, data collection, and causal analysis of the land use model) are documented in the first volume of this report, Growth Effects of Major Land Use Projects, Volume I: Specification and Causal Analysis of Model [5]. Two of the appendices to Volume I (C and D) were published separately [6]. Appendix C contains listings of the data files and simple correlation matrices. Appendix D contains the computer output of the statistical application packages used in the path analysis of the final causal model. The fifth and sixth phases of the study are documented in the second volume of this report, Growth Effects of Major Land Use Projects, Volume II: Compilation of Land Use Based Emission Factors [7].

This final volume of the report, Volume III, summarizes Volumes I and II, documents the fourth phase of the study (i.e., development of the predictive equations of the land use model and development of the traffic model), and serves as a guideline document for the application of the models developed to the task of predicting land use and emissions associated with major land use projects.

B. ORGANIZATION OF VOLUME III

The remainder of this introductory chapter provides an overall summary of the GEMLUP study. Chapters II and III are devoted to the land use model; the first summarizing the model specification, sample selection, data collection, and causal analysis while the latter documents the calibration and validation of the model (i.e., the translation of the causal model into a predictive model. Chapter IV summarizes the land use based emission factors and indices of fuel consumption on which they are based. Chapters V and VI are devoted, respectively to the development of the traffic model and the estimation of motor vehicular emissions. The entire GEMLUP methodology is codified in Chapter VII as a set of computation worksheets and instruction for their use. Finally, Chapter VIII provides an example of these guideline procedures.

There are two appendices to this volume. The first, Appendix A, provides the data necessary to develop confidence intervals for the predictions of the land use model while the second, Appendix B, further documents the cross-validation analysis discussed in Chapter III.

C. SUMMARY

As discussed previously, the GEMLUP study was divided into six phases, each of which is summarized briefly below. A schematic flow diagram of the technical effort is shown in Figure 1-1.

1. Phase 1

The first phase of the study consisted of developing the preliminary hypothesis of induced land use development. This was an elaboration of the following theory:

> Constructing a large source of employment like an industrial/office complex generates jobs which result in the nearby construction of dwelling units; these induce retail development to locate near them and generate demand for community, cultural, and religious facilities (schools, recreation areas, libraries, churches, theaters, fire and police stations, etc.). All of this requires the construction of streets and highways that then improve accessibility to the area. Better access fosters continued urban development, particularly highway-oriented commercial and office land uses. Additional sources of employment come into the area as secondary (and tertiary) industry or services locate near the original major project, spurring on another round of residential development, and so forth.

Concurrently, a determination was made of the input requirements of the traffic model, the estimation of emissions with land use based emission factors, and the availability of data. With these three elements of information, the preliminary hypothesis of induced land use were translated into a specification of a land use model. The model was specified in two separate forms to represent induced land use growth associated with large

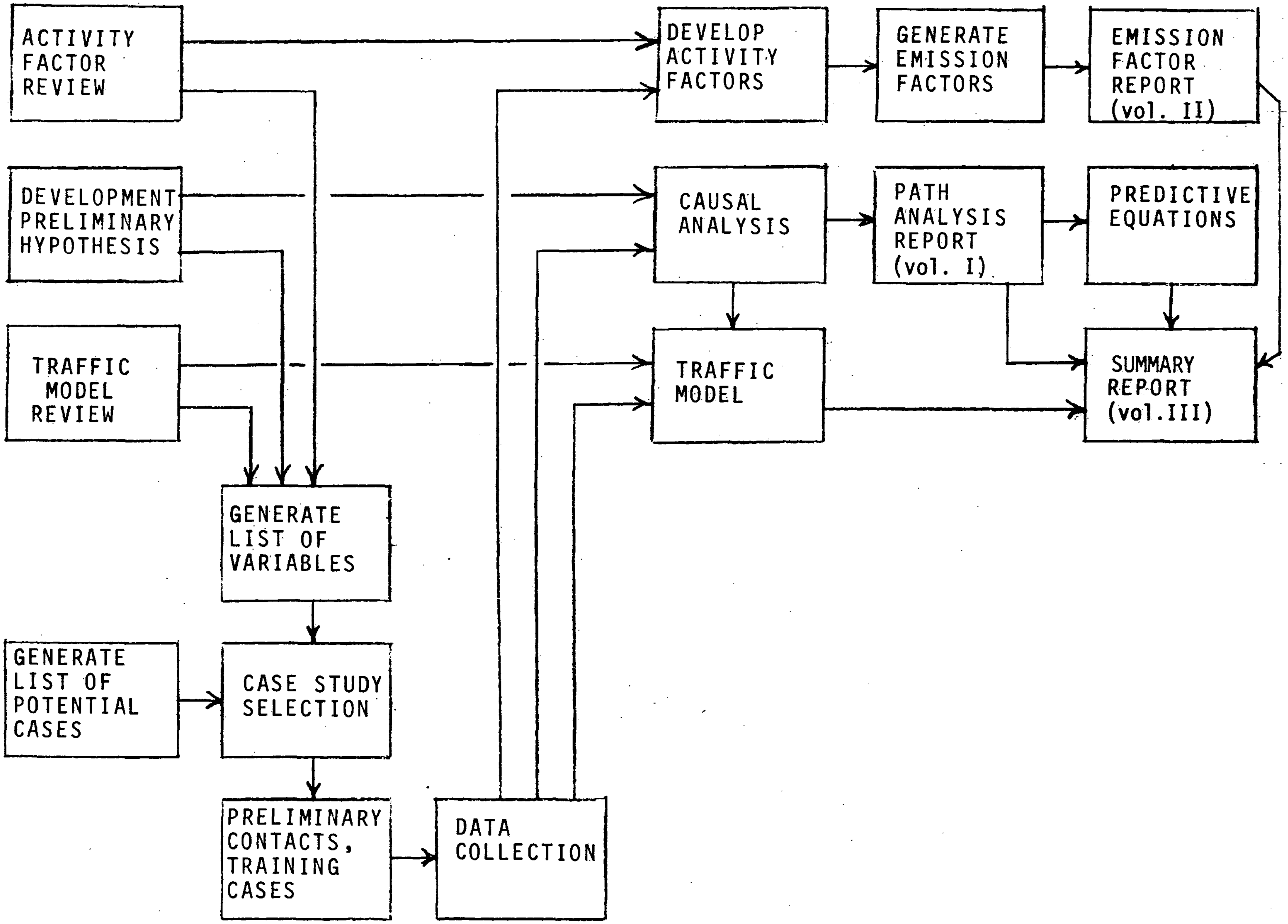

Figure I-1
Flow Diagram of GEMLUP Technical Effort

residential developments, and large Industrial or Office parks in the following 12 land use categories:

Residential	Hotels/Motels
Commercial	Hospitals
Office	Cultural
Manufacturing	Churches
Highways	Education
Wholesale/Warehouse	Recreation

The models predict the land use in a 10,000 acre acrea of influence ten years after construction of the Major Project. Note that the models predict the total land use in the area of influence in each of the twelve categories, not just the induced land use.*

Concurrent with the specification of the land use model, forty case studies were selected (twenty of each major project type), based on various criteria relating to geographical location, major project size and phasing, and data base availability.

2. Phase 2

The second phase of the study was the collection of the requisite data, as identified by the specification of the model. After a test-training case, this data collection phase was composed of two distinct tasks. The first was a site visit which included interviews with individuals at the regional planning agency and, if feasible, the developer. During the site visit, aerial photograph interpretation was performed of the area of influence. The second task was the collection of requisite Census data.

3. Phase 3

The assumption of a single basic causal structure for induced development, and the use of cross-sectional data from diverse locations

*The change in land use over the ten year period can be found by subtracting the current land use from the estimated land use ten years in the future. This change in land use would include the land use induced by the major project as well as land use change due to general regional growth.

throughout the United States, allowed a static approach to the testing of the theoretical models, using path analysis. Path analysis is a set of statistical techniques useful in testing theories and studying the logical consequences of various hypotheses involving causal relations. It is not capable of deducing or generating causal relations, only testing them.

The causal analysis of induced land use development in the current study involved the use of two basic statistical techniques: two-stage least squares and stepwise ordinary least squares (multiple regression). The first technique was required to produce consistent estimates of the path coefficients in a system of simultaneous equations involving feedback loops or reciprocal causation in the models. The second technique was used to solve the remaining recursive portions of the models. The dependent variables in these regression analyses represented the total land use in the previously noted 12 categories. Both linear and non-linear forms were tested and the linear form was found to produce the best fit. Specific statistical criteria were developed to identify model paths that were insignificant or redundant, and these criteria were used to trim unneeded and undesirable paths from the models. A second complete path analysis was performed, and the trimming process repeated several times until the final path models were decided upon. The trimming process eliminated almost half of the paths in the models as originally specified.

The final models of land use development show that strong statistical relationships exist between the variables representing the 12 categories of total land use and the other model variables representing induced and non-induced land use growth processes. Only in the case of cultural land use did the path analysis reject the hypothesized causal relationships. Excluding this category, the R^2 statistic for the model equations in the simultaneous block ranged from 0.43 to 0.81 with an average value of 0.66 and the R^2 values for the model equations in the recursive block ranged from 0.12 to 0.86 with an average value of 0.41. These statistics can be interpreted as the amount of variance in the dependent variables (total land use) of the model equations that can be explained through the linear relationships in the final causal model. These results indicate a good verification of the hypothesized land use development model.

There were several problems encountered in the path analysis, involving multicollinearity, suppressor variables, choice of instrumental variables, available degrees of freedom, and coefficient instability. The first two problems were eliminated through the approach used for theory trimming of the models. The last three problems were caused principally by a common element: the small number of data samples (20) available for analysis. In the model equations, as originally specified, there were sometimes as many independent variables as data samples. Since at least several degrees of freedom should be reserved for the error term in any multiple regression, some model paths had to be trimmed prior to, and in order to perform, the first path analysis. Thus, the limited data sample did preclude the testing of causal relationships in some instances. Also, an analysis of the stability of the model path coefficients revealed appreciable instability in the individual model coefficients when it was applied to different subsets of the original land use data set. We note that this instability does not invalidate the strong causal relationships confirmed by the path analysis.

4. Phase 4

a. Model Calibration

The development of predictive equations for land use development, separate from the model equations obtained in the causal analysis, was necessitated by the simultaneity of the causal relationships, i.e., the causal equations include independent variables whose values will not be known in the future. Therefore, it was necessary to develop predictive equations in which the endogenous variables appeared only as the dependent variables. Such an assumption defined a system of equations which was solved with ordinary least squares analysis. Because of the poor performance of some of the exogenous variables in the causal analysis, the representations of these variables were reconsidered and several new independent variables formulated for use in the development of the predictive equations. In order to systematically decide which variables to include in the predictive equations, stepwise regression techniques were employed and objective statistical criteria applied to obtain predictive equations for the 12 categories of total land use analyzed in the causal analysis.

Summary statistics indicate the predictive equations explain the majority of variance in the dependent variables. The overall F statistics indicate practically all of the predictive equations are significant at or below the one percent level. The results for the coefficient of variation, however, were less encouraging indicating that the average error encountered in the use of these predictive equations will be ± 87 percent of the predicted value. In an attempt to reduce the coefficients of variation for some of the predictive equations, the dependent variables RES, COMM, OFFICE, and MANF were defined in a second manner which did not exclude the dwelling units or land use of the major project from the variables. Predictive equations using these dependent variables were found to be less statistically significant, however.

Predictive equations were also developed for land use at a finer level of detail, where, in addition to the 12 types of land use, the size range (or density) of development for each type was used to categorize the land use being predicted. The equations for disaggregated land use were found to be in general not statistically significant. Therefore, average percentage figures for these subcategories were developed instead. In addition to attempting to disaggregate the 12 categories of land use, predictive equations were developed for an aggregated variable representing the total developed floor area in the area of influence (including the major project). The statistical results for these equations indicate that there is a certain advantage to predicting total land use using an aggregated predictive equation, as opposed to summing together the predicted levels of 12 individual predictive equations and a projection of the major project size.

The validity of any set of predictive equations depends upon their generality. The preferred test of an equation's validity is an external validation, viz., applying it on a test case basis to an independent sample of data (i.e., independent of the sample on which the coefficient values were based) and observing its predictive ability. In the current study a separate, independent sample was not available. Therefore, the analytical technique of cross-validation was used to simulate the existence of such a test sample. This procedure involved splitting both the Residential and Industrial/Office data samples of 20 into two random samples of 10 each. The first 10 samples were used to recompute the coefficient values of the predictive equations and the second 10 samples were used as the independent test sample. Statistical comparisons were then made between actual and predicted values for the dependent variables in the second sample of 10. The results indicate that about half of the 24 predictive equations are generalized enough to produce good predictions using an independent sample. Considering the extremely small sample size (10) used in the cross-validation and the large amounts of variance in the dependent variables, it was encouraging to obtain significant correlations between actual and predicted values in as many equations as we did. The equations that did not perform well in the cross-validation are not necessarily useless. The poor correlations obtained could simply be due to nonhomogeneity in the data sample caused by the extremely small sample size. It was not possible to ascertain if this was the case without a larger, independent sample.

b. Traffic Model

The development of the traffic model included both the development of a methodology to predict the vehicle miles traveled (VMT) by motor vehicular activity induced by the major project and induced land uses as well as the specification of default values for use in the methodology.

The basic methodology for predicting VMT is well known, viz.,

- Estimate vehicle trips by multiplying the amount of land use by vehicle trip generation rates, and
- Estimate VMT by taking the product of the vehicle trips and an estimated trip length.

The important decisions in developing the methodology were then the amount of disaggregation to employ. These included,

- What kinds of trips should be treated separately with respect to trip lengths and trip rates,
- What vehicle classes should be considered,
- How mass transits should be considered,
- How to estimate average route speed.

The final methodology considered two types of trips, (i.e., work and non-work) in four vehicle classes with six different average route speeds i.e., (local streets, arterial, and expressways in peak hour and off peak conditions). The impact of mass transit was assumed to be negligible.

5. Phases 5 and 6

Phases 5 and 6 were devoted to the compilation of a set of land use based emission factors appropriate for use in the GEMLUP methodology. For this reason, manufacturing emissions received less attention than otherwise might have been appropriate.

The land use based emission factor was specified as grams of pollutant per building floor area. This ratio may conveniently be expressed as the product of two ratios, a fuel based emission factor (i.e., the typical emission factor presented in AP-42 [8]), and an activity factor or fuel consumption per building floor area. As the former ratio is well known, the emphasis of Phases 5 and 6 were devoted to quantifying the fuel consumption per unit of building floor area in each of the categories of induced land use.

II. LAND USE MODEL SPECIFICATION AND CAUSAL ANALYSIS

This chapter discusses the specification and causal analysis of the land use model, as well as sample selection and data collection. It is a summary of the first volume of the GEMLUP Final Report [5].

A. GENERAL APPROACH

1. Theory of Induced Development

Taking the industrial/office major land use project type as the more general case of the two types investigated, we adopted the following theory of induced development.

Constructing a large source of employment like an industrial/office complex generates jobs which result in the nearby construction of dwelling units; these induce retail development to locate near them and generate demand for community, cultural, and religious facilities (schools, recreation areas, libraries, churches, theaters, fire and police stations, etc.). All of this requires the construction of streets and highways that then improve accessibility to the area. Better access fosters continued urban development, particularly highway-oriented commercial and office land uses. Additional sources of employment come into the area as secondary (and tertiary) industry or services locate near the original major project, spurring on another round of residential development, and so forth.

2. Selection of General Approach

The selection of an approach for testing this theory was tempered by programmatic considerations. The approach that was selected consisted of a cross-sectional model that predicts the total land use in the vicinity of a major project ten years after development of a major land use project.

3. <u>Statement of Fundamental Model</u>

The basic theory of induced development may be restated as follows: the amount induced land use is some function of the size of the Major Development Project and certain other variables, viz.,

induced land use = f (major project, other variables)

As indicated previously, the approach used in this study limits one to the use of endogenous variables that measure the total land use at the end of the ten year time period. Conceptually, one can disaggregate the total land use in the area of influence into three components, land use existing prior to the development of the major project, new land use induced by the major project and certain other variables, and new land use not induced by the major project (that is, attributable to some other phenomena such as general regional growth). This may be expressed as:

total land use = prior land use +
project induced land use change +
non-project induced land use change

In predicting the total land use in an area of influence, one can identify two types of exogenous variables:

Type I - Those used for predicting the induced land use component, such as,

- The size of the major project,
- The induced component of the endogenous variables of other land uses,
- Other independent variables influencing the effect of the major project (i.e., housing vacancy t+0).

Type II - Those used for predicting the prior or non-induced land use component,

- The prior and non-induced component of the endogenous land use variables,

- Those used for predicting the prior land use component (i.e., 1960 housing density),
- Those used for predicting the non-induced component (i.e., regional population growth).

Accordingly, the fundamental model that we have assembled is:

$$\begin{aligned}\text{land use}_{t+10} &= \text{prior}_{t+0} + \text{induced}_{t+0 \rightarrow t+10} \\ &\quad + \text{non-induced}_{t+0 \rightarrow t+10} \\ &= f(\text{Type I variables, Type II variables}).\end{aligned}$$

We note that both the distinctions between the three land use components and the two variable types are unavailable to this study. The three land use components are not measurable; also, several of our independent variables are possibly of both types.

B. LAND USE MODEL SPECIFICATION

1. Objective

The objective of this phase of the project was to specify an initial land use model explaining induced or associated land use ten years after the construction and operation of a major project. The basic theory underlying the development of the model was that major projects have certain associated or induced land uses and these land uses can be predicted based on the characteristics of the major project and the area in which it locates. However, because of the approach to testing this model, it is necessary to include all land uses in the vicinity of the major project, whether they were induced or not induced, or even existing prior to the construction of the major project.

Two types of major projects were to be considered in the formulation of the model, residential projects and office/industrial projects. Because of the differing land uses associated or induced by these types of projects, a separate model was constructed for each. Thus, two models were developed, one explaining induced or associated land uses ten years after the construction and operation of a major residential project; the other explaining induced or associated land uses ten years after the construction and operation of a major industrial/office project.

2. Definition of Major Project

For purposes of the model specification, a major residential project was defined as housing facilities, planned unit developments or new towns containing a minimum population of 4,500; a major industrial/office project was defined as an office or industrial park or a research and development complex with a minimum employment of 2,250. Both types of projects were initially assumed to reach nearly 80 percent occupancy within two years of operation. However, during case study selection, the definition of major project was somewhat relaxed to permit phased projects.

In addition, for purposes of calibrating the model, the case studies to be analyzed were required to be projects built between 1954 and 1964. The induced or associated land uses were those as of the year 1970; i.e., the year by which it was assumed that the land use impacts of the project had stabilized.

Based on a consideration of the typical size of potential major projects relative to the potential size of the area of influence, it was deemed appropriate to specify a fixed size for the area of influence. A 10,000 acre (4.0×10^7 square meters) area of influence was selected.

3. Model Specification Methodology

The specification of the model was based on (1) a literature search to identify methodologies and case studies which had been used to determine land uses associated with major projects and (2) the prior experience of personnel with land use planning and forecasting, land use models, impact analyses, and large development projects.

4. Model Description

a. Endogenous Variables

Due to the requirements of the emission factors, the units of the endogenous variables for both the residential model and the industrial/office model are building floor area (except for residential and outdoor recreation land uses and highway lane miles) in each of 12 land use categories. These land case categories are residential, retail, office, manufacturing, wholesale and warehousing, hotel, hospital, cultural, churches, public education, outdoor active recreation, and highway lane miles. These particular categories evolved from a process which balanced the following considerations:

- What land use output was needed for estimating emissions,
- What land use output could most effectively be predicted using a causal model, and
- What land use output would be available during data collection to calibrate the model.

The model endogenous variables are defined in Table 2-1.

b. Exogenous Variables

The model consists of 23 independent variables. These variables represent (the numbers refer to the order in Table 2-1):

- Population housing and employment characteristics (variables 13, 14, 16, 18, 19, 20, 21, 25, 26, 27, 28, 29, 30, 34),
- Accessibility measures (variables 17, 22, 24)
- Developability measure (variable 15)
- Regional influences (variables 23, 31, 32, 33, 35)

The independent variables for each equation were selected because of their perceived causal relationship with the dependent variables.

TABLE 2-1

MODEL VARIABLES AND DEFINITIONS

1. RES = Number of housing units in area of influence in 1970 (excluding major project).

2. COMM = Commercial land use in area of influence in 1970 in 1,000 square feet

   Commercial land use includes the following land use codes (LUC) as used by the Public Service Administration Service in its 1962 Land Use Classification Manual.

   LUC 52-59 Retail trade
   61 Personal services
   63 Automobile service
   64 Miscellaneous repair service
   65 Indoor amusement service

3. OFFICE = Office land use in area of influence (excluding major project) in 1970 in 1,000 square feet

   LUC 60 Finance, Insurance, Real Estate
   62 Business services
   67 Medical, Health, Legal services
   68 Other professional services

4. MANF = Manufacturing land use in area of influence (excluding major project) in 1970 in 1,000 square feet

   LUC 2 Nondurable goods manufacturing
   3 Durable goods manufacturing

5. WHOLE = Wholesale/warehouse land use in area of influence in 1970 in 1,000 square feet

   LUC 50 Wholesale
   46 Warehousing

6. HOTEL = Hotel and motel land use in area of influence in 1970 in 1,000 square feet

   LUC 07 Hotels, Motels, Tourist Homes

7. HOSPTL = Hospital, etc., land use in area of influence in 1970 in 1,000 square feet

   LUC 77 Hospitals, Sanatoria, Convalescent Homes and Rest Homes

TABLE 2-1 (CONTINUED)
MODEL VARIABLES AND DEFINITIONS

8.	CULTUR	= Cultural land use in area of influence in 1970 in 1,000 square feet LUC 76 Museums, Libraries, Art Galleries, except, Churches (764) Arboreta (762) Cemeteries (767)
9.	CHURCH	= Religious land use in area of influence in 1970 in 1,000 square feet LUC 764 Churches 765 Other religious services
10.	EDUC	= Public educational land use in area of influence in 1970 in 1,000 square feet LUC 74 Public Schools
11.	REC	= Active outdoor recreational land use in area of influence in 1970 in acres
12a.	HWLMNX	= Highway lane miles in area of influence in 1970, excluding limited access highways
12b.	HWLM	= Highway lane miles in area of influence in 1970
13a.	MPR70	= Residential land use in major project in 1970 in dwelling units
13b.	MPR68	= Residential land use in major project in 1968 in dwelling units
13c.	MPRt2	= Residential land use in major project in base year plus two (t+2) in dwelling units
14.	DUACRE	= Dwelling units per acre in area of influence in 1960
15.	VACACR	= Percent vacant developable acreage in area of influence in year (t+0)
16.	VACHSG	= Percent vacant housing in area of influence in 1960
17.	HWYINT	= Highway interchanges in area of influence in year (t+5)

TABLE 2-1 (CONTINUED)

MODEL VARIABLES AND DEFINITIONS

18.	MINCC	= Median income of families and individuals in area of influence relative to U.S. median income in 1960
19.	INCMP	= Variable indicating the median income level of major project compared to surrounding community in year (t+2)
20.	OFFVAC	= Percent office buildings vacant in metropolitan area in year (t+0)
21.	OFFACR	= Office employment per acre in area of influence in year (t+0)
22.	DISCBD	= Distance from center of major project to CBD in year (t+0)
23.	ENERGY	= Cost factor for electricity (S/1500 kWh) for commercial users in the metropolitan area in year (t+0) divided by the average U.S. commercial rate in 1960
24.	RRMI	= Railroad mileage in area of influence in year (t+0)
25.	WWEA	= Warehouse and wholesale employment per acre in area of influence in year (t+0)
26.	EMPACR	= Total employment per acre in area of influence in year (t+0)
27.	NONHSE	= Nonhousehold population per acre in area of influence in 1960
28.	MPKIDS	= School-age children per dwelling unit in major project in year (t+2)
29.	ENRACR	= Public school enrollment per acre in area of influence in 1960
30.	MANACR	= Manufacturing employment per acre in area of influence in year (t+0)
31.	DELPOP	= Growth factor for total regional population between 1960 and 1970 (county data)
32.	DELEMP	= Growth factor for total regional employment between 1960 and 1970 (county data)

TABLE 2-1 (CONTINUED)

MODEL VARIABLES AND DEFINITIONS

33.	MINCR	= Median income of the region in year (t+0) relative to the median U.S. income in 1960
34a.	MPE70	= Number of employees in major project in 1970
34b.	MPE68	= Number of employees in major project in 1968
34c.	MPEt2	= Number of employees in major project in base year (t+2)
35.	AUTO	= Automobile drivers per acre in county in 1960

Prior to selecting these variables a complete list of all possible factors influencing the dependent variable was prepared. From this list the most significant variables were identified.

The specific format for each independent variable was developed based on 1) availability of data, 2) consistency of data among case studies, and 3) the appropriate time period for the data.

c. Equations

Twelve equations were specified to predict each of the twelve endogenous variables. In both models (i.e., the residential model and the industrial/office model), five of these equations are simultaneous. The remaining seven equations are recursive.

C. SAMPLE SELECTION

1. Purpose and Initial Criteria

The purpose of the sample selection process was to identify for each type of major project a sample of case studies which could be used in the testing and calibration of the model. Once a list of qualified case studies was prepared, the actual selection of the final sample took place. This selection process involved consideration of factors such as availability of information, particularly aerial photographs and geographic location of the project. The final list of case studies is shown for the industrial/ office and residential sample in Table 2-2.

D. DATA COLLECTION

Following the specification of the model, a list of data items required for the model was prepared. This was supplemented with additional items potentially useful in the model calibration phase of this project.

The data collection process consisted of two simultaneous phases. The first was an on-site visit which primarily consisted of interviews with the local and regional planning agencies, the developer (if available), and

TABLE 2-2

CASE STUDIES

Industrial	Residential
Farmington Park, Farmington, CT	Joppatown, Hartford County, MD
Western Electric, North Andover, MA	Montgomery Village, MD
Avco, Wilmington, MA	Kings Park, Fairfax County, VA
IBM, Kingston, NY	Vienna Woods, Fairfax County, VA
Ft. Washington, Philadelphia, PA	Deltona, FL
Keystone Park, Scranton, PA	Miami Lakes, Miami, FL
Crestwood Park, Wright Turnpike, PA	Town'n Country, Tampa, FL
General Electric, Salem, VA	Montclair-Starmount, Charlotte, NC
Cummings Park, Huntsville, AL	Weathersfield, Schaumberg, IL
IBM, Lexington, KY	Oak Park, Blaine, MN
Collins Radio Park, Cedar Rapids, IA	Cottage Grove, MN
Ford, Woodhaven, MI	Clear Lake City, Harris County, TX
Western Electric, Columbus, OH	Meyerland, Houston, TX
White-Westinghouse, Columbus, OH	Westwood Heights, Omaha, NE
Little Rock Industrial Park, Little Rock, AR	Northglenn, CO
Chrysler, Fenton, MO	Sun City, Maricopa, AZ
Western Electric, Omaha, NE	Foster City, CA
Motorola, Phoenix, AZ	Huntington Harbour, Orange County, CA
Tektronix, Washington County, OR	Sun City, Perris, CA
Honeywell, Phoenix, AZ	Rancho Bernado, CA

the collection of locally available data. This data consisted primarily of building floor area of various categories of land uses in the area of influence obtained by aerial photograph interpretation. The second phase consisted of the collection of 1960 and 1970 Census of Population and Housing Data for the area of influence.

E. CAUSAL ANALYSIS

1. General Approach

The approach to path analysis in the current study involved the use of two basic statistical techniques: two-stage least squares and ordinary least squares multiple regression. The first technique was used to solve for path coefficients in the system of five equations connected by feedback loops. For a given dependent variable, the first stage of the two-stage process involved estimating the values of the other four endogenous variables through linear combinations of so-called instrumental variables which are chosen for their causal relationships with the endogenous variables.

To solve for path coefficients in the other model equations that were not interconnected, ordinary least squares regression techniques were used.

2. Data Transformations

The land use and demographic data collected in the field program were loaded into a field data file on our computer system for processing. Computations were performed on these data to create the model variables chosen for path analysis. These data transformations are summarized in a list of variable definitions in Table 2-3.

Analyses were subsequently performed on model variables to test for multicollinearity, possible suppressor variable problems, and the suitability of instrumental variables (used in solving feedback loops). The model was trimmed as a result of the investigations and the first path analysis performed.

TABLE 2-3

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable

---

1. RES = Residential land use in area of influence in 1970 (excluding major project) in dwelling units

   RES = du70t - mpr70

   where: du70t = dwelling units in area of influence in 1970

   mpr70 = residential land use in major project in 1970 in dwelling units

2. COMM = Commercial land use in area of influence in 1970 in 1,000 square feet

   COMM = (comm1 + comm2 + comm3 + comm4)/10

   where: comm1 = 100 square feet commercial in area of influence in 1970 (<25K)

   comm2 = 100 square feet commercial in area of influence in 1970 (25-50K)

   comm3 = 100 square feet commercial in area of influence in 1970 (50-100K)

   comm4 = 100 square feet commercial in area of influence in 1970 (>100K)

3. OFFICE = Office land use in area of influence (excluding major project) in 1970 in 1,000 square feet

   OFFICE = (off1 + oof2 + off3)/10

   where: off1 = 100 square feet office in area of influence (excluding major project) in 1970 (<50K)

   off2 = 100 square feet office in area of influence (excluding major project) in 1970 (50-100K)

   off3 = 100 square feet office in area of influence (excluding major project) in 1970 (>100K)

4. MANF = Manufacturing land use in area of influence (excluding major project) in 1970 in 1,000 square feet

   MANF = manf/10

   where: manf = 100 square feet manufacturing in area of influence (excluding major project) in 1970

TABLE 2-3 (CONTINUED)

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable
5. WHOLE = Wholesale/warehouse land use in area of influence in 1970 in 1,000 square feet WHOLE = whole/10 where: whole = 100 square feet wholesale/warehouse in area of influence in 1970
6. HOTEL = Hotel and motel land use in area of influence in 1970 in 1,000 square feet HOTEL = (hotel1 + hotel2 + hotel3 + hotel4)/10 where: hotel1 = 100 square feet hotel in area of influence in 1970 (<25K) hotel2 = 100 square feet hotel in area of influence in 1970 (25-50K) hotel3 = 100 square feet hotel in area of influence in 1970 (50-100K) hotel4 = 100 square feet hotel in area of influence in 1970 (>100K)
7. HOSPTL = Hospital, etc., land use in area of influence in 1970 in 1,000 square feet HOSPTL = (hosp1 + hosp2 + hosp3)/10 where: hosp1 = 100 square feet hospitals in area of influence in 1970 (25-50K) hosp2 = 100 square feet hospitals in area of influence in 1970 (50-100K) hosp3 = 100 square feet hospitals in area of influence in 1970 (>100K)
8. CULTUR = Cultural land use in area of influence in 1970 in 1,000 square feet CULTUR = cultur/10 where: cultur = 100 square feet cultural in area of influence in 1970
9. CHURCH = Religious land use in area of influence in 1970 in 1,000 square feet CHURCH = church/10 where: church = 100 square feet religious in area of influence in 1970

TABLE 2-3 (CONTINUED)

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable		
10.	ED	= Educational land use in area of influence in 1970 in 1,000 square feet
	ED	= (ed1 + ed2 + ed3)/10
		where: ed1 = 100 square feet education in area of influence in 1970 (<25K)
		ed2 = 100 square feet education in area of influence in 1970 (25-50K)
		ed3 = 100 square feet education in area of influence in 1970 (>100K)
11.	REC	= Active outdoor recreational land use in area of influence in 1970 in acres
12.	HWLM	= Highway land miles in area of influence in 1970
12a.	HWLMNX	= Highway lane miles in area of influence in 1970 without expressways
13.	MPRT2	= Residential land use in major project in year t+2 in dwelling units
13a.	MPR68	= Residential land use in major project in 1968 in dwelling units
13b.	MPR70	= Residential land use in major project in dwelling units
14.	DUACRE	= Dwelling units per acre in census tracts in 1960
	DUACRE	= (du60c - mpr60)/ac60c
		where: du60c = dwelling units in census tracts
		ac60c = census tract acreage in 1960
		mpr60 = dwelling units in major project in 1960
15.	VACACR	= Percent vacant developable acreage in area of influence in year (t+0)
	VACACR	= vacdev/(10,000-vacund)
	VACUND	= Vacant undevelopable acreage in area of influence in year (t+0)
		where: vacdev = vacant developable acreage in area of influence in year (t+0)

TABLE 2-3 (CONTINUED)

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable
16. VACHSG = Percent vacant housing in census tracts in 1960 VACHSG = vac60c/du60c where: vac60c = Vacant available housing units in census tracts in 1960
17. HWYINT = Highway interchanges in area of influence in year (t+0)
18. MINCC = Median income factor for families and individuals in census tracts relative to average U.S. income in 1960 MINCC = mincc/$5,650 where: mincc = Median income for families and individuals
19. INCMP = Variable indicating the median income level of major project compared to surrounding community in year (t+2) INCMP = incmpa - incmpb where: incmpa = +1 if major project median income ≥15 percent above that of surrounding community incmpb = +1 if major project median income ≥15 percent below that of surrounding community
20. OFFVAC = Percent office buildings vacant in metropolitan area in year (t+0)
21. OFFACR = Office employment per acre in area of influence in year (t+0) OFFACR = offemp/10,000 where: offemp = Office employment in area of influence in year (t+0)
22. DISCBD = Distance from center of major project to CBD in year (t+0) in miles
23. ENERGY = Cost factor for electricity ($/1500 kWh) for users in the metropolitan area in year (t+0) relative to the average U.S. commercial rate in 1960 ENERGY = energy/$51.59 where: energy = Dollars per 1500 kWh for commercial users in metropolitan area in year (t+0)

TABLE 2-3 (CONTINUED)

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable
24. RRMI = Railroad mileage in area of influence in year (t+0)
25. WWEA = Warehouse and wholesale employment per acre in area of influence in year (t+0)
WWEA = wwemp/10,000
where: wwemp = Warehouse and wholesale employment in area of influence in year (t+0)
26. EMPACR = Total employment per acre in area of influence in year (t+0)
EMPACR = totemp/10,000
where: totemp = total employment in area of influence in year (t+0)
27. NONHSE = Nonhousehold population per acre in census tracts in 1960
NONHSE = (p60c - hp60c)/ac60c
where: p60c = Total population in census tracts in 1960
hp60c = Household population in census tracts in 1960
28. MPKIDS = School-age children per dwelling unit in major project in year (t+2)
29. ENRACR = Public school enrollment per acre in census tracts in 1960
ENRACR = p1460c/ac60c
where: p1460c = Population under 14 years of age in census tracts in 1960
30. MANACR = Manufacturing employment per acre in area of influence in year (t+0)
MANACR = manemp/10,000
where: manemp = Manufacturing employment in area of influence in year (t+0)
31. DELPOP = Growth factor for total regional population between 1960 and 1970 (county data)
DELPOP = (p70cty - p60cty)/p60cty
where: p70cty = Total population in county in 1970
p60cty = Total population in county in 1960

TABLE 2-3 (CONTINUED)

PATH ANALYSIS MODEL DATA TRANSFORMATIONS

Model Variable		
32.	DELEMP	= Growth factor for total regional employment between 1960 and 1970 (county data)
	DELEMP	= (e70cty - e60cty)/e60cty
		where: e70cty = Total employment in county in 1970
		e60cty = Total employment in county in 1960
33.	MINCR	= Median income factor for the region in year (t+0) relative to the average U.S. income in 1960
	MINCR	= mincr/$5,660
		where: mincr = Median income for the region in the year (t+0) (county data)
34.	MPET2	= Number of employees in major projects in year (t+2)
34a.	MPE68	= Number of employees in major projects in year 1968
34b.	MPE70	= Number of employees in major projects in year 1970
35.	AUTO	= Automobile drivers per acre in county in 1960
	AUTO	= au60cy/ac60cy
		where: au60cy = Automobile drivers in county in 1960
		ac60cy = County acreage in 1960

3. Theory Trimming

The results of the first path analysis revealed many path coefficients that were too low or of the wrong sign as predicted from theory. In addition, the overall t-statistics of several of the model equations indicated no statistical significance at the five percent level. Thus, criteria were developed which when applied to the numerical output of the first path analysis trimmed many model paths. A second path analysis was performed, and the process repeated several times until a final path model was decided upon. This recursive procedure was necessitated by the fact that trimming one variable often causes significant changes in the path coefficients of the remaining variables.

In trimming the path analysis model, the following rules were applied. A path was trimmed if:

- $|t|$ or $F < 1.0$, and $\beta < 0.1$, and loss of the variable would not cause the loss of a significant instrumental variable in the first stage estimations,
- The sign of path coefficients (β) was wrong and counter to the original path model hypothesis.

In addition, some paths whose statistics indicated they should be trimmed were kept if the sign of the path coefficients (β) was correct and the variables were very important causally in the path model. Finally, the discovery of $\beta > 1.0$ in a few model equations indicated correlations between the independent variables to the extent that some paths were redundant. In these instances, simple correlations between the various path coefficients were computed and the most highly correlated variable was trimmed. Correlation coefficients were calculated from the variance-covariance matrix of the estimated coefficients by dividing the covariance of the coefficients of the two variables in question by the product of their individual standard deviations.

The results of the two-stage least squares and the ordinary least squares regressions performed for the final path analysis are presented in Figures 2-7 and 2-8 for the Residential and Industrial/Office Models,

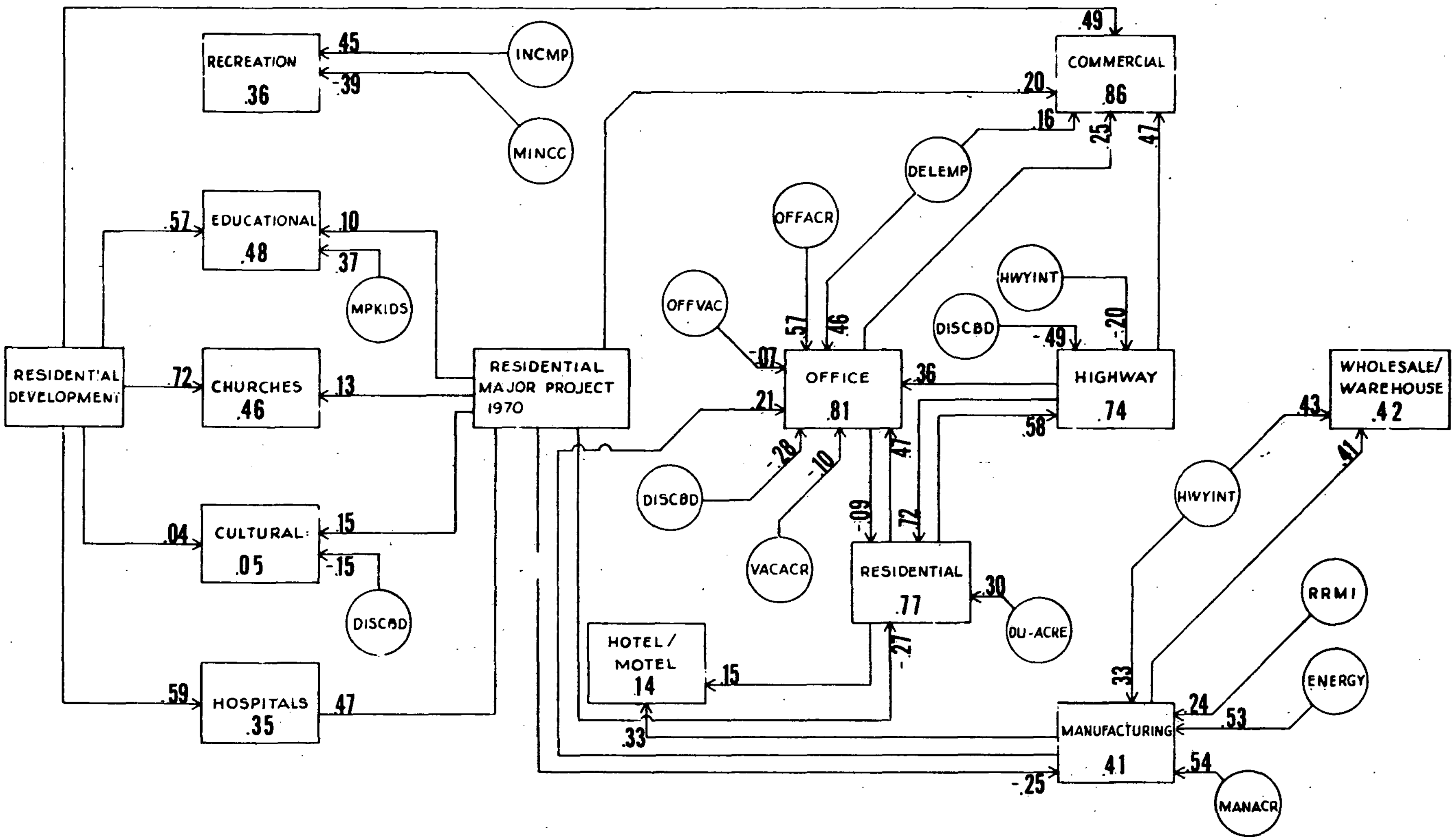

Figure 2-7 Final Path Analysis for the Residential Model

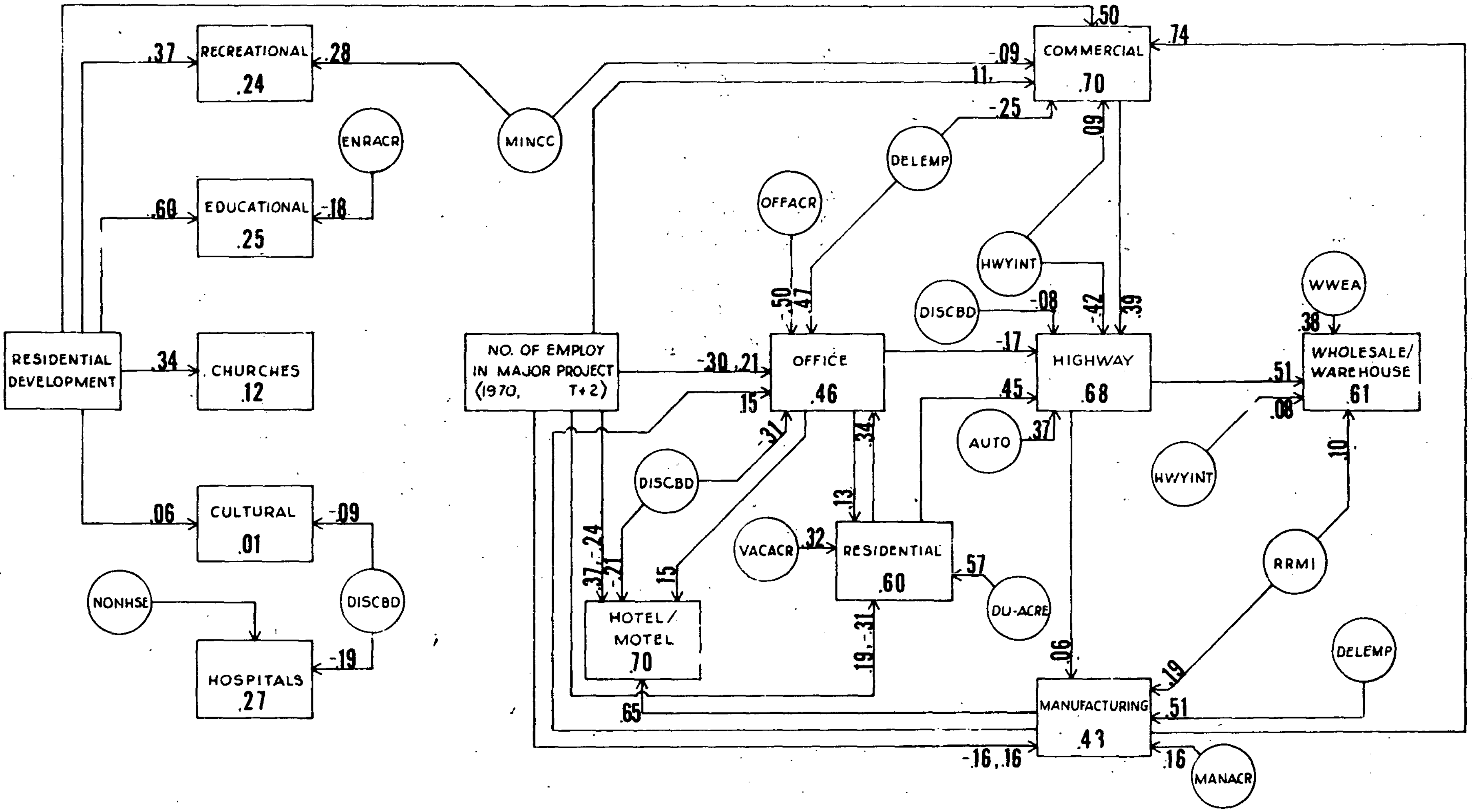

Figure 2-8 Final Path Analysis for the Industrial-Office Model

respectively. The path coefficients (β) are shown on each path and the R^2 for each regression is displayed next to the associated dependent variable. For each equation, the effect on the dependent variable of all residual causes can be quantified by the path coefficient for residual causes, defined as:

$$\beta_\varepsilon = (1-R^2)^{1/2}$$

a. Summary of Final Model Equations in Unstandardized Form

The final model equations are summarized below with unstandardized coefficients.

(1) English Units

(a) Residential Model

RES = - 1.38 OFFICE + 168 HWLMNX - 0.808 MPR70 + 3930 DUACRE + 2730
COMM = 0.0814 RES + 0.649 OFFICE + 18.4 HWLMNX + 0.0976 MPR70 - 692
OFFICE = - 0.0319 RES + 5.74 HWLMNX + 0.0572 MANF - 0.0127 VACACR
- 5.26 OFFVAC + 690 OFFACR - 15.4 DISCBD + 765 DELEMP + 421
MANF = 1470 MANACR + 316 HWYINT + 4100 ENERGY - 0.176 MPR70 + 79.8 RRMI
- 3940
HWLMNX = 0.00247 RES - 3.31 HWYINT - 1.73 DISCBD + 47.9
WHOLE = 60.4 HWYINT + 0.0608 MANF + 26.5
HOTEL = 0.00151 RES + 0.0140 MANF + 49.3
HOSPTL = 0.0106 RES + 0.0246 MPR70 - 61.6
CULTUR = 0.00014 RES + 0.00154 MPR70 - 0.447 DISCBD + 19.5
CHURCH = 0.0134 RES + 0.00716 MPR70 + 13.3
EDUC = 0.0392 RES + 209 MPKIDS + 0.0203 MPR70 - 137
REC = 329 INCMP - 563 MINCC + 826

(b) Industrial/Office Model

RES = 3.96 OFFICE - 0.859 MPET2 + 0.392 MPE70 + 4560 DUACRE
+ 1.05 VACACR - 4860

COMM = 0.0785 RES + 0.413 MANF + 0.0367 MPE70 + 39.1 HWYINT - 2270 DELEMP - 290 MINCC - 45.2

OFFICE = 0.0110 RES + 0.0178 MANF - 0.0199 MPE70 + 0.0195 MPET2 - 285 OFFACR - 8.11 DISCBD + 902 DELEMP + 174

MANF = 4.55 HWLMNX + 0.124 MPET2 - 0.0974 MPE70 + 55.6 RRMI + 8690 DELEMP + 1020 MANACR - 22.5

HWLMNX = 0.00178 RES - 0.0209 OFFICE + 0.00980 COMM - 4.59 HWYINT - 0.246 DISCBD + 32.6 AUTO + 14.3

WHOLE = 10,500 WWEA + 34.7 HWLMNX + 29.0 RRMI + 64.6 HWYINT - 1120

HOTEL = 0.0524 MANF + 0.105 OFFICE + 0.0182 MPE70 - 0.0156 MPET2 - 4.04 DISCBD - 26.0

HOSPTL = 508 NONHSE - 5.66 DISCBD + 108

CULTUR = 0.0023 RES - 0.249 DISCBD + 13.6

CHURCH = 0.00513 RES + 51.1

EDUC = 0.0405 RES + 304

REC = 0.0149 RES + 242 MINCC - 184

(2) Metric Units. As can be seen in Tables 2-1 and 2-3, the model variables were defined and the path analyses carried out in English units. Thus, the path regression coefficients given for each equation in the previous section reflect this fact. The path diagrams in this section, however, display the path coefficients (β) which are independent of the units chosen.

This section summarizes the final model equations for variables RES, COMM, OFFICE, MANF, WHOLE, HOSPTL, CULTUR, CHURCH, AND EDUC. The variables REC and VACACR also use m^2 but in place of acres. Distances in miles in HWLMNX, DISCBD, and RRMI are converted to km. Finally, the units of $acre^{-1}$ are replaced by m^{-2} in the variables DUACRE, OFFACR, WWEA, EMPACR, NONHSE, ENRACR, MANACR, DELEMP, and AUTO.

The conversion factors used were:

1,000 ft^2	$\rightarrow m^2$	*by 92.90
acres	$\rightarrow m^2$	*by 4,047

miles → m^2 *by 1.609
$acre^{-1}$ → m^{-2} *by 4047

(a) Residential Model

RES = - 1.38 OFFICE = 9700 HWLMNX - 75.1 MPR70 + 1,480,000,000 DUACRE
+ 254,000
COMM = 0.0814 RES + 0.649 OFFICE + 1,060 HWLMNX + 9.07 MPR70
- 260,000,000 DELEMP - 12,900
OFFICE = - 0.0319 RES + 331 HWLMNX + 0.0572 MANF - 0.000292 VACACR
- 489 OFFVAC + 260,000,000 OFFACR - 889 DISCBD + 2
+ 288,000,000,000 DELEMP
MANF = 553,000,000 MANACR + 29,400 HWYINT + 381,000 ENERGY - 16.4 MPR70
+ 4,610 RRMI - 366,000
HWLMNX = 0.0000428 RES - 5.33 HWYINT - 1.73 DISCBD + 771
WHOLE = 5,610 HWYINT + 0.0608 MANF + 2,460
HOTEL = 0.00151 RES + 0.0140 MANF + 4,580
HOSPTL = 0.0106 RES + 2.29 MPR70 - 5,720
CULTUR = 0.00014 RES + 0.143 MPR70 - 2.58 DISCBD + 1.810
CHURCH = 0.0134 RES + 0.665 MPR70 + 1,240
EDUC = 0.0392 RES + 19,400 MPKIDS + 1.89 MPR70 - 12,700
REC = 1,330,000 INCMP - 2,280,000 MINCC + 3,340,000

(b) Industrial/Office Model

RES = 3.96 OFFICE - 79.8 MPET2 + 36.4 MPE70 + 1,710,000,000 DUACRE
+ 0.0241 DUACRE - 451,000
COMM = 0.0785 RES + 0.413 MANF + 3.41 MPE70 + 3.630 HWYINT
- 853,000,000 DELEMP - 26,900 MINCC - 4,200
OFFICE = 0.0110 RES + 0.0178 MANF - 1.85 MPE70 + 1.81 MPET2
- 107,000,000 OFFACR - 468 DISCBD + 339,000,000 DELEMP + 16,200
MANF = 263 HWLMNX + 11.5 MPET2 - 9.05 MPE70 + 3,210 RRMI
+ 3,270,000,000 DELEMP + 383,000,000 MANACR - 2,090
HWLMNX = 0.0000308 RES - 0.000362 OFFICE + 0.000170 COMM - 7.39 HWYINT
- 0.246 DISCBD + 212,000 AUTO + 23.0

$$WHOLE = 3{,}948{,}000{,}000\ WWEA + 2{,}000\ HWLMNX + 1.670\ RRMI + 6{,}000\ HWYINT - 104{,}000$$

$$HOTEL = 0.0524\ MANF + 0.105\ OFFICE + 1.69\ MPE70 - 1.45\ MPET2 - 233\ DISCBD - 2{,}420$$

$$HOSPTL = 191{,}000{,}000\ NONHSE - 327\ DISCBD + 10{,}000$$

$$CULTUR = 0.0023\ RES - 14.4\ DISCBD + 1{,}260$$

$$CHURCH = 0.00513\ RES + 4{,}750$$

$$EDUC = 0.0405\ RES + 28{,}200$$

$$REC = 0.649\ RES + 979{,}000\ MINCC - 745{,}000$$

III. <u>DEVELOPMENT OF LAND USE MODEL PREDICTIVE EQUATIONS</u>

A. APPROACH

The development of predictive equations for land use development, separate from the model equations obtained in the causal analysis, was necessitated by the simultaneity of the causal relationships. Since the endogenous variables (to be predicted for some future time period) appear as both independent and dependent variables in the causal model equations, these equations clearly can not be used for operational, predictive purposes. Or more simply, these causal equations include independent variables whose values will not be known in the future. Therefore, it was necessary to develop predictive equations in which the endogenous variables appeared only as the dependent variables. Such an assumption defines a system of equations which can be solved with ordinary least squares analysis.

When predictive equations are developed using ordinary least squares for variables which are known to be effected by simultaneity, the <u>individual</u> regression coefficients have expectations equal to the true structural parameter, plus a function of the variables left out of the regression; that is, they are biased estimates of the true structural parameters (see Section VI.A of Volume I [5]). However, the <u>final prediction</u> of the equation is an unbiased estimate of the dependent variable. Since these equations are to be used for predictive and not analytical purposes, the fact that the individual coefficients are biased estimates was not of great concern. It must be emphasized therefore, that the regression coefficients obtained for the predictive equations should not be examined to judge the effects of independent variables on the dependent variable, nor should these coefficients be compared with those obtained in the causal analysis. Rather the appropriateness of a predictor can only be determined by examining its performance with regard to a set of objective statistical criteria.

In order to systematically decide which variables to include in the predictive equations, stepwise regression techniques were employed. The dependent variables in this stepwise regression analyses were the 12 categories of total land use analyzed in the causal analysis:

- Residential
- Commercial
- Office
- Manufacturing
- Highways
- Wholesale/Warehouse
- Hotels/Motels
- Hospitals
- Cultural
- Churches
- Education
- Recreation

The independent variables included in the stepwise regression analysis for predictive equations were separated into two sets. The first set (1) included all instrumental variables used in the causal model which best predicted the endogenous variables in the first stage of the 2-stage least squares procedure (see Table 3-1) and those exogenous variables which were significant in the final path analysis. The second set (2) of independent variables included all other exogenous variables from the original specification of the models (shown in Table 3-2) as well as many new independent variables, discussed in the next Section III.B.

The approach to developing predictive equations involved two stepwise regression analyses. The first analysis performed allowed all variables from set (1) with a statistically significant F statistic to enter the regression equation before any variables from set (2) were considered. The second analysis included both sets of independent variables (1) and (2) at the same level of consideration. In the analyses, an F ratio test was used at each step of the multiple regression procedure to determine whether the reduction in the residual sum of squares due to the added variable was statistically significant. The critical F value used was 1.8, i.e., an independent variable was added into the regression if its F ratio equalled or exceeded 1.8. This critical value corresponds approximately to the

TABLE 3-1

INSTRUMENTAL VARIABLES USED IN THE FINAL PATH ANALYSIS

	Residential Model	Industrial/Office Model
1.	DUACRE	DUACRE
2.	OFFACR	MINCC
3.	DISCBD	OFFACR
4.	MPR70	DISCBD
5.	VACACR	MANACR
6.	OFFVAC	MPE70
7.	HWYINT	VACACR
8.	DELEMP	RRMI
9.	MANF	OFFVAC
10.	--	AUTO
11.	--	HWYINT
12.	--	DELEMP
13.	--	MPET2

TABLE 3-2

EXOGENOUS VARIABLES INCLUDED IN THE ORIGINAL MODEL SPECIFICATIONS BUT TRIMMED PRIOR TO THE FINAL PATH ANALYSIS

Model Equation	Exogenous Variables
Residential Model	
RES	VACACR, VACHSG, DELPOP, MPRT2, MPR68
COMM	INCMP, MINCR, MINCC, HWYINT, MPRT2, MPR68
OFFICE	HWYINT, MPRT2, MPR68, MPR70
MANF	DELEMP, MPRT2, MPR68
HWLMNX	EMPACR, AUTO, MPRT2, MPR68, MPR70
WHOLE	DELEMP, RRMI, WWEA
HOTEL	EMPACR, DISCBD, MPRT2, MPR68, MPR70
HOSPTL	DISCBD, NONHSE, MPRT2, MPR68
CULTUR	MPRT2, MPR68
CHURCH	MPKIDS, MPRT2, MPR68
EDUC	ENRACR, MPRT2, MPR68
REC	MPRT2, MPR68, MPR70
Industrial/Office Model	
RES	DELPOP, VACHSG, MPE68
COMM	MINCR, MPET2, MPE68
OFFICE	OFFVAC, VACACR, HWYINT, MPE68
MANF	HWYINT, ENERGY, MPE68
HWLMNX	EMPACR, MPET2, MPE68, MPE70
WHOLE	DELEMP
HOTEL	EMPACR, MPE68
HOSPTL	MPET2, MPE68, MPE70
CURTUR	---
CHURCH	---
EDUC	ENRACR
REC	---

10 percent level of significance, i.e., there was at most a 10 percent chance of accepting a variable as significant in the regression when it actually was not.

For each dependent variable, the final predictive equation chosen from the many possible forms generated by the stepwise regression analyses was the one with the highest adjusted R^2 value which had six or less predictors, each with an F statistic significant at the 10 percent level or better, and none having a β value greater than 1.0. The adjusted R^2 is defined as:

$$R^2_a = R^2 - \left(\frac{k-1}{N-k}\right)(1-R^2)$$

where:

R^2 = coefficient of determination

k = number of independent variables

N = number of data samples

The conventional R^2 statistic can yield deceptive results when the significance of specific predictors is in question. For example, simply adding a variable to any regression equation, whether it is at all correlated with the dependent variable or not, will raise the R^2 and indicate additional variance has been explained. The R^2_a gives a more conservative, unbiased estimate of the amount of variance explained in the dependent variable through the regression equation. In cases where two forms had nearly identical R^2_a values, the one containing more causally important variables (i.e., set (1) variables) was chosen. The maximum limit of six variables was set to keep the predictive equations simple, avoid possible degrees of freedom problems, and keep the confidence intervals small. In addition, examination of the results of the stepwise analyses showed that in most cases, the first six variables explained most, if not all, of the variance of the dependent variable that could be explained by including more independent variables. The requirement that each individual predictor have a significant F statistic eliminated the situation where the inclusion of a new variable in an equation caused the individual F statistics of previously entered variables to drop below the critical value of 1.8. The restriction on β values was used to avoid multicollinearity in the regression analyses which might cause instability in the regression coefficients. One further criterion used in simplifying the equations was that an independent variable was not included unless its presence caused a noticeable reduction in the coefficient of variation from the previous step (viz., a minimum of two-three percent change). The coefficient of variation is defined as the ratio of the standard error of estimate of the regression to the mean value of the dependent variable. A detailed discussion of the results of the regression analyses is given in Section III.C.

B. NEW VARIABLE DEFINITIONS

Based upon the poor performance of some of the exogenous variables in the causal analysis, the representations of these variables were reconsidered and several new independent variables formulated for use in the development of the predictive equations.

The variable DELPOP was defined in a second manner, on a growth per acre basis:

DELP2 = (p70cty-p60cty)/ac60cy*

We believe that whenever regional population growth is large, there is increased demand for all types of land use development. Thus, this new variable was included in all of the predictive equations.

Due to the variation in the cost of living across the U.S., areas with the same MINCC or MINCR values may have different standards of living. To eliminate this problem, a new variable MINC was defined to indicate whether the median income of the area of influence was above or below that for the region. This variable was defined as:

MINC = mincc/mincr

*See Table 2-3 for a definition of all lower-case variables in this and subsequent equations which are not defined.

This new variable was included in all of the predictive equations but RES, MANF, and WHOLE. Since RES represents total dwelling units in the current model, and not housing value or acreage, it is doubtful that a relationship exists between RES and MINC.

Due to the poor performance of HWYINT in the causal analysis, the data collected was examined and it was discovered that in 40 percent of the samples HWYINT = 0, with a maximum value of 6 occurring. HWYINT is an indicator of the presence of limited-access expressways in the area of influence. Due to the small area of influence in the current study (10,000 acres), it is doubtful that the presence of multiple highway interchanges induces more land use development than the presence of just one. Therefore, a new variable HWYLIM was defined to indicate whether a limited-access highway is present or not in the area of influence.

$$\text{HWYLIM} = \begin{array}{l} 0 \text{ if HWYINT} = 0 \\ 1 \text{ if HWYINT} > 0 \end{array}$$

This new variable was included in the predictive equations for RES, COMM, OFFICE, MANF, WHOLE, HOTEL, and HWLMNX.

The variable AUTO was included in the model equation for HWLMNX on the theory that the density of auto drivers per acre effects the construction of highway facilities. Since AUTO was not found to be causally important in the HWLMNX equation in the Residential model, a new variable AUTO2 was defined to represent motor vehicle density in a different way as auto drivers per dwelling unit:

AUTO2 = au60cy/du60cy

where: du60cy = total dwelling units in county in 1960. (input data card 7, columns 11-16)*

This new variable was included in the predictive equations for HWLMNX.

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* See Sections V and VI.B in Volume I [5] for a discussion of the data collection and formatting tasks.

Another new variable related to highway development, TRIPS, was defined to represent the amount of trip generation per dwelling unit from a residential major project. Since specific trip generation data were not available, a metric variable of arbitrary units related to the income level of the major project was used instead (see Section V). The new variable was defined as:

$$\text{TRIPS} = \begin{cases} 1 \text{ if INCMP} = -1 \\ 3 \text{ if INCMP} = 0 \\ 5 \text{ if INCMP} = 1 \end{cases}$$

The variable TRIPS was only included in the predictive equation for HWLMNX in the Residential model.

The indicator variable INCMP as defined for the causal analysis assumed that residential major projects with a median income more than 15 percent above or below that of the surrounding community had equal but opposite effects in inducing development, relative to a major project with a median income equal to that of the surrounding community. This metric assumption placed an unrealistic constraint on the variable. Therefore, two new indicator variables INCMPL and INCMPH were defined to represent the low and high income effects separately. These new variables were defined as:

$$\text{INCMPL} = \begin{cases} 1 \text{ if INCMP} = -1 \\ 0 \text{ if INCMP} = 0 \text{ or } 1 \end{cases}$$

$$\text{INCMPH} = \begin{cases} 1 \text{ if INCMP} = 1 \\ 0 \text{ if INCMP} = 0 \text{ or } -1 \end{cases}$$

The variables INCMPL and INCMPH were only included in the predictive equations for COMM and REC in the Residential model.

The variable DELEMP was included in the model equations to account for development associated with regional employment growth. Due to its poor performance in the causal analysis, a new variable EMP60 was defined to represent the absolute level of regional employment in 1960, rather than the growth in employment from 1960 to 1970. This new variable was defined as:

EMP60 = e60cty

The variable EMP60 was included in the predictive equations for COMM, OFFICE, MANF, and WHOLE.

The variable VACACR was included in the model equations for RES and OFFICE to represent developable acreage in the area of influence (excluding the major project). Vacant developable land is a prime factor encouraging new land use development. Unfortunately, VACACR performed poorly in the causal analysis. A possible explanation for this variable's failing in the causal analysis may be ascribed to vacant acreage in the major project, developed between the year t+0 and 1970. Note that the total land use variables RES and OFFICE for which relationships were hypothesized in the causal analysis exclude the acreage of the major project. Therefore, any variable introduced into a model equation to explain recent development included in these land use totals must be corrected for all influences of the major project. In the causal analysis a correction was made by defining VACACR to exclude all acreage under the control of the major project developer. However, the major project probably had a secondary effect on new land use development that was not corrected for. Suppose for example that an area contained a large amount of developable acreage outside the major project in year t+0. Even in an area favorable to new development, little if any may have occurred between the year t+0 and 1970 if the major project grew substantially in this time period. In other words, the area had a certain fixed development potential in residential or office land use for the period t+0 to 1970. Any group considering development in this area in the year t+0 probably took account of the effect of planned development announced for the already existing major project on this potential market. Therefore, a new vacant acreage variable VAC2 was defined in which the proportion of major project land developed between the year t+0 and 1970 is subtracted out from non-major project developable acreage to correct for this effect. This new variable was defined as:

$$\text{VAC2} = \begin{cases} \text{VACACR} - \dfrac{\text{MPR70-MPRT2}}{\text{MPR70}}\ \text{mpdev} & \text{in the Residential model} \\ \text{VACACR} - \dfrac{\text{MPE70-MPET2}}{\text{MPE70}}\ \text{mpdev} & \text{in the Industrial/Office model} \end{cases}$$

The variable VAC2 was included in the predictive equations for RES and OFFICE.

One other new vacant acreage variable VAC3 was defined that took account of land area zoned for other than residential, commercial, etc., uses. This variable was defined as:

VAC3 = 10,000-mpdev-mpund-(100 zother)

where: zother = percent of total acreage in the area of influence zoned for other than residential, commercial, industrial, or office use in year t+5

(card input 4, columns 56-58)

Note that the variable vacund was not included in this equation because of possible overlap between land areas classified as undevelopable and zoned for other uses. The variables VAC3 was included in the predictive equations for RES and OFFICE.

Two new variables were developed to represent the size of a major project differently from the MPR and MPE variables used in the causal analysis. The first of these, DENSE, measures the housing density of residential major projects, and is defined as:

DENSE = MPR70/mpdev

The second variable, MPACRE, measures the land area of the major projects, and is defined as:

MPACRE = mpdev

The variable DENSE was included in all predictive equations in the Residential model. The variable MPACRE was included in all predictive equations. One additional new variable MPTIME was developed to represent the relative amount of time a major project had to induce development before 1970. This variable was defined as:

MPTIME = 1970 - base yr

where: base yr = the base year t when the major project first opened (input card 1, columns 13-14)

The variable MPTIME was included in all predictive equations.

The variables MANF and OFFICE were included in the model equations for RES and COMM to represent development demand associated with growth in manufacturing and office employment. Unfortunately these variables did not perform very well in the causal analysis. Therefore, two exogenous variables, MANACR and OFFACR, representing the amount of manufacturing and office employment, respectively, in the area of influence in the year t+0 were included in the predictive equations for RES and COMM, and additionally in the HOTEL equations.

The equations for HOTEL, HOSPTL, CULTUR, and REC had fairly low R^2 values in the causal analysis, suggesting that the variables included in the equations did not represent the principal causes of these forms of development. Therefore, additional relationships were hypothesized and included in the predictive equations for these categories of land use. The new variables are defined below:

DISAIR = Highway distance in miles to nearest major airport in year t+0 (input card 4, columns 29-32)

AIRPRT = 1 if an airport existed within 3.23 miles of the center of the major project in the year t+0

0 otherwise (input card 3, column 66)

PVTSCH = 1 if a private school existed within 3.23 miles of the center of the major project in the year t+0

0 otherwise (input card 3, column 64)

UNIV = 1 if a university existed within 3.23 miles of the center of the major project in the year t+0

0 otherwise (input card 3, column 62)

WATER = 1 if a five square mile body of water existed within 3.23 miles of the center of the major project in the year t+0

0 otherwise (input card 3, column 70)

COAST = 1 if a sea coast existed within 3.23 miles of the center of the major project in the year t+0

0 otherwise (input card 3, column 68)

The variables DISAIR, AIRPRT, UNIV and MINC were added to the HOTEL equations. Airport accessibility and area income level can both directly effect hotel development. The presence of a university can also effect hotel development, but indirectly through the accommodation requirements of families visiting students and professionals attending conferences. The variable UNIV was added to the HOSPTL equation since the presence of a nearby medical school favors the creation of research and hospital medical facilities. The variables PVTSCH, UNIV and MINC were added to the CULTUR equations. The presence of a private school or university, and the area income level can all directly effect the development of cultural activities. The variables WATER and COAST were added to the REC equations to account for the presence of these major recreation-attracting natural features.

One type of data gathered in the data collection phase of this study that was not utilized in the causal analysis was land use zoning classifications. New variables representing the proportion of acreage zoned in various categories were defined as follows:

ZRES = percent of total acreage in the area of influence zoned for residential use in the year t+5

ZRES = zressf + zresmf

where: zressf = percent of total acreage in the area of influence zoned for single-family residential use in the year t+5 (input card 4, columns 45-47) zresmf = percent of total acreage in the area of influence zoned for multi-family residential use in the year t+5 (input card 4, columns 48-49)

ZCOMM = percent of total acreage in the area of influence zoned for commercial use in the year t+5 (input card 4, columns 50-51)

ZOFF = percent of total acreage in the area of influence zoned for office use in the year t+5 (input card 4, columns 52-53)

ZIND = percent of total acreage in the area of influence zoned for industrial use in the year t+5 (input card 4, columns 54-55)

The variables ZRES, ZCOMM, and ZOFF were included in the predictive equations for RES, COMM, and OFFICE, respectively. The variable ZIND was included in the predictive equations for MANF and WHOLE. The rationale in each case was that development is directly controlled by the zoning classifications set in each area.

In many areas of the country, the construction of public sewers by cities and towns is used like zoning to guide land use development. Therefore, a new variable SEWER was defined as follows:

SEWER = percentage of land in the nearest municipality which had public sewerage available in the year t+5. (input card 4, columns 42-44)

The variable SEWER was included in all of the predictive equations.

C. DISCUSSION OF RESULTS

The predictive equations obtained by applying the previously discussed objective criteria to the stepwise regression analyses are summarized in Section III.D. Summary statistics for these equations are shown in Table 3-3. The number of predictors in each equation varies from one to six with an average of from three to four. R^2_a values indicate the predictive equations are explaining the majority of variance in the dependent variables. The mean value for this statistic of 0.54 can be considered quite good in view of the fact that the regressions were performed on a relatively small (20) sample of cross - sectional data. The overall F statistics indicate practically all of the predictive equations are significant at or below the one percent level. The results for the coefficient of variation, however, are less encouraging. The values of this statistic range from 0.34 to 1.73 with a mean of 0.87. Since this statistic expresses the standard error of estimate of the regression relationship as a percentage of the dependent variable mean value, a value as close as zero as possible is desirable. The summary statistics indicate that the average error encountered in the use of these predictive equations will be ± 87 percent of the predicted value. An examination of the statistics in Table 3-3 show that high values for the coefficient of variation often occur when the R^2_a of the regression is low, as would be expected.

In an attempt to reduce the coefficients of variation for some of the predictive equations, the dependent variables RES, COMM, OFFICE and MANF were defined in a second manner which did not exclude the dwelling units or land use of the major project from the variables. In the Residential model, the major project represents residential land use and so the only new dependent variable tested was RES* defined as:

RES* = total dwelling units in the area of influence in 1970. (input card 5, columns 49-53).

In the Industrial/Office model, three new dependent variables were created, defined as:

OFFICE* = total office floor area in the area of influence in 1970 in 1,000 ft^2.

MANF* = total manufacturing floor area in the area of influence in 1970 in 1,000 ft^2.

WHOLE* = total wholesale and warehouse floor area in the area of influence in 1970 in 1,000 ft^2.

TABLE 3-3

SUMMARY STATISTICS OF PREDICTIVE EQUATIONS

Dependent Variable	Number of Predictors	Sample R^2	R^2_a	Significance Level of Overall F Statistic*	Coefficient of Variation
Residential Model					
RES	6	0.72	0.62	0.005	0.81
COMM	6	0.82	0.76	0.001	0.49
OFFICE	5	0.81	0.76	0.001	0.67
MANF	3	0.30	0.22	0.15	1.44
HWLMNX	5	0.69	0.61	0.005	0.74
WHOLE	5	0.79	0.73	0.001	0.79
HOTEL	3	0.70	0.66	0.001	0.54
HOSPTL	2	0.38	0.34	0.025	1.34
CULTUR	2	0.49	0.47	0.005	0.94
CHURCH	2	0.41	0.38	0.025	0.91
EDUC	4	0.65	0.58	0.005	0.58
REC	1	0.43	0.43	0.005	1.63
Industrial/Office Model					
RES	5	0.82	0.77	0.001	0.34
COMM	4	0.78	0.73	0.001	0.48
OFFICE	5	0.66	0.57	0.01	0.69
MANF	3	0.47	0.41	0.025	0.84
HWLMNX	4	0.65	0.59	0.005	0.47
WHOLE	4	0.77	0.73	0.01	0.95
HOTEL	3	0.46	0.40	0.025	1.04
HOSPTL	3	0.51	0.46	0.01	1.73
CULTUR	4	0.43	0.32	0.10	1.31
CHURCH	4	0.48	0.38	0.05	0.73
EDUC	3	0.46	0.39	0.025	0.60
REC	6	0.75	0.66	0.005	0.88

* A significance level of 0.01 indicates there is at most a one percent chance (using the two-tail test) that the population R^2 for the regression equation is 0.

where: OFFICE* = OFFICE + 43.56 mpdev (percent OFFICE + percent R&D)/100

MANF* = MANF + 43.56 mpdev (percent MANF/100)

WHOLE* = WHOLE + 43.56 mpdev (percent WHOLE/100)

and where,

Percent R&D = percent of the developed land in the major project used for research and development purposes.

Percent OFFICE = percent of the developed land in the major project used for office purposes (input card 1, columns 73-73)

Percent MANF = percent of the developed land in the major project used for manufacturing purposes (input card 1, columns 67-69)

Percent WHOLE = percent of the developed land in the major project used for wholesale and warehousing purposes (input card 1, columns 76-78)

mpdev = total developed land area of the major project in acres

Due to the exclusion of major project land use from the dependent variables RES, COMM, OFFICE, and MANF, these variables experienced a large variance in value with zero values occurring a significant percentage of the time, indicating in these cases that the major project contained all of a certain type of land use in the area of influence. By including the major project land use in the variables being predicted, we had hoped to reduce the resultant coefficients of variation in two ways. First, the effect of including major project land use was to eliminate zero values and so significantly reduce the variance that needed to be explained in the regression relationships, and secondly, this inclusion also raised the mean value of these dependent variables. Predictive equations for the four total land use variables RES* COMM* OFFICE* and MANF* were obtained by applying the techniques used discussed in Section III.A.

A comparison of the summary statistics for the predictive equations in which land use of the major project is included or excluded from the dependent variable is shown in Table 3-4. The results show that for two of the four modified variables, RES* and WHOLE*, lower coefficients of variation are obtained. An examination of the regression statistics, however, reveals that most of this change is due solely to the increase in the mean value of the dependent variable, and not due to lower standard errors of estimate. In addition, three of the four overall F statistics indicate less significance (higher percent level) for the "*" regressions, and in general, the R^2_a values are lower. Based on these results, therefore, use of the original predictive equations excluding major project land use are recommended. The equations for RES*, OFFICE*, MANF*, and WHOLE* are, however, summarized in the following Section III.D, along with the equations for the other dependent variables, for reference purposes.

Due to the relatively large coefficients of variation and low R^2_a values for some of the predictive equations (e.g., the MANF equation in the Residential model and the CULTUR equation in the Industrial/Office model), it may be tempting for the user to selectively substitute the equation forms developed in the causal analysis. Examination of the statistics for these equations, however, show them to be no more significant. Due to the fact that the predictive equations have the smallest possible variance of all linear estimators and only they produce unbiased estimates of the dependent variables, the causal equations should not be used for predictive purposes. Use of the causal equations would also probably result in cumulative errors of estimation from the use of endogenous variables as predictors.

The predictive equations shown below in Section I.D, constitute a set of equations applicable to areas where a major project (Residential or Industrial/Office) will be or already has been built. They do not constitute a general land use predictive model. The data values that will be used for the

TABLE 3-4

COMPARISON OF SUMMARY STATISTICS FOR PREDICTIVE EQUATIONS IN WHICH LAND USE OF THE MAJOR PROJECT IS INCLUDED OR EXCLUDED FROM THE DEPENDENT VARIABLE

Dependent Variable +	Number of Predictors	Sample R^2	Sample R_a^2	Significance Level of Overall F Statistic	Coefficient of Variation
Residential Model					
RES*	5	0.66	0.60	0.01	0.47
RES	6	0.72	0.62	0.005	0.81
Industrial/Office Model					
OFFICE*	2	0.35	0.32	0.025	1.87
OFFICE	5	0.66	0.57	0.01	0.69
MANF*	4	0.46	0.35	0.05	0.73
MANF	3	0.47	0.41	0.025	0.84
WHOLE*	5	0.87	0.83	0.001	0.68
WHOLE	4	0.77	0.73	0.001	0.95

+ A suffix of "*" on a variable indicates that it includes the floor area of the major project.

major project variables MPR70 and MPE70 where they appear in the predictive equations will, therefore, correspond to the projected final size of the major project in the area of influence. The data values for MPET2 and MPR68 will correspond to the size of the major project two years after initiation and two years before completion, respectively. Examination of the predictive equations reveals that the major project variables do not appear as often as one would expect, based upon the relationships verified in the causal analysis. This fact indicates that for some types of land use, just the presence of a large major project, and not necessarily its size, induces a certain amount of land use development. The predictive equations developed in this study are based upon data collected in areas containing a large major project, viz., one containing several thousand dwelling units (Residential Model) or employing several thousand employees (Industrial/Office Model). Specifically, based upon the mean and standard deviations of the variables MPR70 and MPE70 representing final major project size:

- A Residential project should be in the range of 1,100-5,300 total dwelling units, and
- An Industrial/Office project should be in the range of 3,600-9,100 employees.

The use of these equations should be limited to situations in which the major project is in this size range. Also, any application of the predictive equations should be qualified by the error range indicated by the coefficients of variation shown in Table 3-3.

D. SUMMARY OF PREDICTIVE EQUATIONS

1. English Units

a. Residential Model

RES = 8,910 DUACRE + 6,790 DELP2 - 351 DISCBD - 1,360 HWYINT + 41.2 SEWER - 0.682 MPR70 + 7,200

RES* = 8,880 DUACRE + 6,110 DELP2 - 343 DISCBD - 1,346 HWYINT + 42.5 SEWER + 8,270

COMM = 791 OFFACR - 73.7 DISCBD + 656 DUACRE - 200 HWYINT + 0.00327 EMP60 + 0.0647 VACACR + 1,380

OFFICE = 845 OFFACR + 601 DELEMP - 14.1 DISCBD - 400 DUACRE + 85.8 HWYINT + 355

MANF = 1,050 MANACR + 761

HWLMNX = - 2.79 DISCBD + 40.5 DELP2 - 135 AUTO2 + 46.6 MINC + 0.00595 MPR68 + 78.8

WHOLE = 97.1 HWYINT - 0.0736 MPR70 - 269 DUACRE - 11.4 DISCBD + 15.0 OFFVAC + 488

HOTEL = - 0.968 ZRES + 230 AUTO - 150 INCMPL + 81.7

HOSPTL = 191 OFFACR + 0.0196 MPR70 - 23.9

CULTUR = 60.2 UNIV + 0.00175 VACACR + 2.54

CHURCH = 202 MINC - 4.42 DISCBD - 14.7

EDUC = 0.0408 VACACR + 2.46 SEWER - 25.5 DISCBD + 184 MPKIDS + 244

REC = 0.103 MPACRE - 33.5

b. Industrial/Office Model

RES = 2,480 DUACRE + 205 VACACR + 563 OFFVAC - 128,000 VACHSG - 406 DISCBD - 9,530

COMM = 869 DUACRE + 119 ZCOMM - 2,090 OFFACR + 0.0553 MPE70 - 838

OFFICE = 11.5 RRMI + 68.9 ZOFF - 0.0273 MPE70 + 507 MINC + 254 MANACR - 326

OFFICE*= 13.2 MPACRE + 8,120 DELPOP - 2,540

MANF = 10,100 DELEMP - 2,620 MINCC + 0.252 VACACR + 1,120

MANF* = 0.911 MPE70 - 7,010 DUACRE + 466 RRMI - 417 DISCBD + 9,430

HWLMNX = 0.00385 VACACR - 6.08 HWYINT + 19.6 DUACRE + 1.70 OFFVAC - 25.7

WHOLE = 7,470 WWEA + 90.8 ZIND + 11.4 SEWER + 726 DUACRE - 1,650

WHOLE* = 111 ZIND + 955 DUACRE + 2,420 HWYLIM - 435 HWYINT - 0.00227 EMP60 - 1,240

HOTEL = - 11.5 DISCBD + 1,180 DELEMP - 249 OFFACR + 145

HOSPTL = 478 NONHSE + 443 MANACR - 283 OFFACR - 20.5

CULTUR = - 34.6 ENERGY + 0.00004 EMP60 + 0.0411 MPACRE + 12.6 PVTSCH + 23.6

CHURCH = 8.65 RRMI + 0.0314 VACACR - 1.07 SEWER - 0.0146 MPET2 - 148

EDUC = 0.0802 MPET2 + 0.0974 VACACR + 34.8 RRMI - 925

REC = 17.6 OFFVAC + 1,440 DELEMP + 387 MINCC - 615 AUTO + 14.8 DISCBD + 188 MANACR - 604

2. Metric Units

This section summarizes the predictive equations for variables defined in metric units. Specifically m^2 replaces 1,000 ft^2 in the variables RES, COMM, OFFICE, MANF, WHOLE, HOTEL, HOSPTL, CULTUR, CHURCH, and EDUC. The variables REC, MPACRE, VACACR, and VAC3 also use m^2, but in place of acres. Distances in miles in HWLMNX, DISCBD, and RRMI are converted to km. And finally, the units of $acre^{-1}$ are replaced by m^{-2} in the variables DUACRE, OFFACR, WWEA, EMPACR, NONHSE, ENRACR, MANACR, DELEMP, AUTO and DELP2.

The conversion factors used were:

1,000 ft^2	→	m^2	*by 92.90
acres	→	m^2	*by 4,047
miles	→	km	*by 1.609
$acre^{-1}$	→	m^{-2}	÷by 4,047

a. Residential Model

RES = 3,350,000,000 DUACRE + 255,000,000 DELP2 - 20,300 DISCBD - 126,000 HWYINT + 3,830 SEWER - 63.4 MPR70 + 669,000

RES* = 3,340,000,000 DUACRE + 2,297,000,000 DELP2 - 19,800 DISCBD - 125,000 HWYINT + 768,000

COMM = 297,000,000 OFFACR - 4,260 DISCBD + 247,000,000 DUACRE - 18,600 HWYINT + 0.304 EMP60 + 0.00149 VACACR + 128,000

OFFICE = 318,000,000 OFFACR + 226,000,000 DELEMP - 814 DISCBD - 150,000,000 DUACRE + 7,970 HWYINT + 33,000

MANF = 395,000,000 MANACR + 70,700

HWLMNX = - 2.79 DISCBD + 264,000 DELP2 - 217 AUTO2 + 75.0 MINC + 0.00957 MPR68 + 127

WHOLE = 9,020 HWYINT - 6.84 MPR70 - 101,000,000 DUACRE - 658 DISCBD + 1,390 OFFVAC + 45,300

HOTEL = - 89.9 ZRES + 86,500,000 AUTO - 13,900 INCMPL + 7,590

HOSPTL = 71,800,000 OFFACR + 1.82 MPR70 - 2,220

CULTUR = 5,590 UNIV + 0.0000402 VACACR + 236

CHURCH = 18,800 MINC - 255 DISCBD - 1,370

EDUC = 0.000937 VACACR + 229 SEWER - 1,470 DISCBD + 17,100 MPKIDS + 22,700

REC = 417 MPACRE - 136,000

b. Industrial/Office Model

RES = 932,000,000 DUACRE + 0.0471 VACACR + 52,300 OFFVAC
- 11,900,000 VACHSG - 23,400 DISCBD - 885,000

COMM = 327,000,000 DUACRE + 11,100 ZCOMM - 786,000,000 OFFACR
+ 5.14 MPE70 - 77,900

OFFICE = 664 RRMI + 6,400 ZOFF - 2.54 MPE70 + 47,100 MINC
+ 95,500,000 MANACR - 30,300

OFFICE*= 0.302 MPACRE + 754,000 DELPOP - 236,000

MANF = 3,800,000,000 DELEMP - 243,000 MINCC + 0.00579 VACACR + 104,000

MANF* = 84.6 MPE70 - 2,640,000,000 DUACRE + 26,900 RRMI
- 24,100 DISCBD + 876,000

HWLMNX = 0.00000153 VACACR - 9.78 HWYINT + 128,000 DUACRE + 2.74 OFFVAC
- 41.4

WHOLE = 2,810,000,000 WWEA + 8,440 ZIND + 1,060 SEWER + 273,000,000 DUACRE
- 153,000

WHOLE* = 10,300 ZIND + 359,000,000 DUACRE + 225,000 HWYLIM
- 40,400 HWYINT - 0.211 EMP60 - 115,000

HOTEL = - 664 DISCBD + 444,000,000 DELEMP - 93,600,000 OFFACR + 13,500

HOSPTL = 180,000,000 NONHSE + 167,000,000 MANACR - 106,000,000 OFFACR
- 1,900

CULTUR = - 3,210 ENERGY + 0.00372 EMP60 + 0.000944 MPACRE + 1,170 PVISCH
+ 2,190

CHURCH = 499 RRMI + 0.000721 VACACR - 99.4 SEWER - 1.36 MPET2 - 13,700

EDUC = 7.45 MPET2 + 0.00224 VACACR + 2,010 RRMI - 85,900

REC = 71,200 OFFVAC + 23,600,000,000 DELEMP + 1,570,000 MINCC
- 10,100,000,000 AUTO + 37,200 DISCBD + 3,080,000,000 MANACR
- 2,440,000

E. DISAGGREGATION AND AGGREGATION OF LAND USE CATEGORIES

As part of the transformation of collected field data to the desired variables in the causal analysis, land use in many subcategories representing different size ranges were aggregated to form the endogenous variables. For example the endogenous variable OFFICE is defined* as:

OFFICE = office land use in area of influence (excluding major project) in 1970 in 1,000 square feet

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*See Table 2-1.

OFFICE = (off1 + off2 + off3)/10

where: off1 = 100 square feet office in area of influence (excluding major project) in 1970 (<50K)

off2 = 100 square feet office in area of influence (excluding major project) in 1970 (50-100K)

off3 = 100 square feet office in area of influence (excluding major project) in 1970 (>100K)

Once predictive equations were developed for the 12 categories of total land use, our attention turned to the possibility of predicting land use at a finer level of detail, where, in addition to the type of land use, the size range of development was used to categorize the land use being predicted. In other words, we attempted to predict land use at the disaggregated level of off1, off2, and off3, for example.

Of the 12 types of land use analyzed, data were available to disaggregate six of these, corresponding to the variable RES, COMM, OFFICE, HOTEL, HOSPTL, and EDUC. Due to the overall lower R^2_a values of the predictive equations for HOTEL, HOSPTL, and EDUC (see Table 3-3), disaggregation predictions were not attempted for these variables. In addition, the subcategories of OFFICE were not analyzed due to the results from Volume II [7] indicating that energy consumption per floor area (and hence emission rates) are not significantly different for office buildings in different size ranges. Disaggregation analysis was, therefore, performed only for the remaining variables RES and COMM.

Residential land use (dwelling units) was disaggregated into the subcategories.

- Single Family Detached
- Single Family Attached
- Mobile Home
- Multifamily low rise
- Multifamily high rise

Commercial land use (1,000 ft^2) was disaggregated into the subcategories of:

- $<$ 50,000 ft^2
- 50-100,000 ft^2
- $\geq$ 100,000 ft^2

In order to avoid the problem of having the predicted land use in the subcategories not add up to the total land use, variables representing the <u>percent</u> of land use of a certain type in each subcategory were used. The idea was to use the previously discussed predictive equations to project total land use of a certain type and then use the disaggregation equations to predict the percentage breakdown of the total land use among the various subcategories. The variables analyzed were defined as follows:

Percent COMM1, Percent COMM2, Percent COMM3 — the percent of total commercial land use in the area of influence in 1970 occurring in the subcategories of $<$50,000 ft^2, 50-100,000 ft^2, and $>$100,000 ft^2, respectively.

Percent RESSFD, Percent RESSFA, Percent RESMO, Percent RESML, Percent RESMH — The percent of total census tract residential dwelling units in 1970 related to single family detached and attached homes, mobile homes, multi-family low rise structures, and multi-family high rise structures, respectively.

Stepwise regressions were performed to develop predictive equations for the subcategory percentage variables. The objective statistical criteria discussed previously (Section III.A) were used to evaluate the results. Regressions were performed with percent COMM1, percent COMM2 and percent COMM3 as the dependent variables and variables representing median income level (MINC), distance from the central business district (DISCBD), the amount of land zoned for commercial use (ZCOMM), the amount of land with access to a sewer system (SEWER) and the commercial employment per acre (COMEMP) as the independent variables. For the dependent variables percent RESSFD, percent RESSFA, percent RESMO, percent RESML, and percent RESMH, the independent variables in the regressions represented median income level (MINC), distance to the central business district (DISCBD), residential density (DUACRE), amount of land with access to a sewer system (SEWER) and the amount of land zoned for single family and multifamily residential development (ZRESSF and ZRESMF, respectively).

An examination of the summary statistics of the predictive equations for the disaggregation variables indicated that no statistically significant predictors could be found in about half of regressions. In the regressions where significant predictors were chosen, the relationships developed were counter to what one would reasonably expect. For example, MINC (median income level) was found to be negatively related to percent RESSF (the percent of single family structures in total residential land use). Due to the poor results obtained, average percentage figures for each subcategory were computed; these are summarized in Table 3-5. Since these data are representative of the year 1970, and not future years, it is recommended that a projected percentage split for the land use being predicted be developed in each particular case, taking account of both the area and future time period involved. It is doubtful that the average percentages in Table 3-5 take into account the parameters or effects that will guide the densities of commercial and residential development in future years. In the absence of other data, however, the average percentages shown here do provide an estimation of the possible disaggregation of land use development.

In addition to attempting to disaggregate the 12 categories of land use for which predictive equations were developed, these land use variables were <u>aggregated</u> to form a total land use variable TOTUSE, defined as:

TOTUSE = total developed land use in the area of influence (including major project) in 1970 in 1,000 ft^2.

TABLE 3-5

AVERAGE PERCENTAGE VALUES FOR
DISAGGREGATED LAND USE VARIABLES

Disaggregation Variable	Subcategory Description	Major Project Type Residential	Industrial/Office
	Commercial		
Percent COMM1	30,000 ft^2	51%	66%
Percent COMM2	50-100,000 ft^2	20%	14%
Percent COMM3	100,000 ft^2	29%	20%
		100%	100%
	Residential		
Percent RESSFD	single family detached	61%	68%
Pervent RESSFA	single family attached	3%	2%
Percent RESMO	mobile home	6%	6%
Pervent RESML	multifamily low rise	29%	23%
Percent RESMH	multifamily high rise	1%	1%
		100%	100%

TOTUSE = RES* ((1.6 Percent SF/100) + (0.9 Percent MF/100))
+ COMM + OFFICE* + MANF* + WHOLE* + HOTEL +HOSPTL
+ CULTUR + CHURCH + EDUC + 43.56 REC

where:

Percent SF = percent of total residential dwelling units in the area of influence in 1970 related to single family and mobile homes.

Percent MF = percent of total residential dwelling units in the area of influence in 1970 related to multifamily structures.

1.6 = Average 1,000 ft^2 of floor area for a single family dwelling unit

0.9 = Average 1,000 ft^2 of floor area for a multifamily dwelling unit

43.56 = Conversion factor from acres to 1,000 ft^2

Percent SF = res1/restot

Percent MF = (res1 + res2 + res3 + res5 + res50)/restot

where:

res1 = single family home dwelling units in census tracts in 1970 (input card 5, columns 68-73)

res2 = two-family structure dwelling units in census tracts in 1970 (input card 5, columns 74-78)

res3 = three and four-family structure dwelling units in census tracts in 1970 (input card 6, columns 4-8)

res5 = five through 49-family structure dwelling units in census tracts in 1970 (input card 6, columns 9-13)

res50 = 50-and greater family structure dwelling units in census tracts in 1970 (input card 6, columns 14-18)

restot = total year-round dwelling units in census tracts in 1970 (input card 5, columns 62-67)

Stepwise regressions were performed in which TOTUSE was the dependent variable and a composite set of all independent variables used in the predictive equation analysis was used for the independent variables. The regression relationships developed and the associated statistics are summarized in Table 3-6. The results indicate that when the major project type

TABLE 3-6

AGGREGATED TOTAL LAND USE PREDICTIVE EQUATIONS
AND SUMMARY STATISTICS

Residential Model

(English Units) TOTUSE = 2.42 MPACRE + 2,700 ZCOMM + 12,100 ZOFF + 638 DISAIR - 23,100 MINC - 8,390 DUACRE + 4,120

(Metric Units) TOTUSE = 0.0556 MPACRE + 251,000 ZCOMM + 1,120,000 ZOFF + 36,800 DISAIR - 2,150,000 MINC - 3,150,000,000 DUACRE + 383,000

$R^2 = 0.73$ Significance level of overall F statistic = 0.005

$R_a^2 = 0.64$ Coefficient of variation = 0.96

Industrial/Office Model

(English Units) TOTUSE = 31.2 MPACRE + 8,650 OFFACR + 2.06 MPE68 + 28,400 MINCR - 1.85 MPET2 - 25,600

(Metric Units) TOTUSE = 0.716 MPACRE + 3,250,000,000 OFFACR + 191 MPE68 + 2,640,000 MINCR - 172 MPET2 - 2,380,000

$R^2 = 0.84$ Significance level of overall F statistic = 0.001

$R_a^2 = 0.80$ Coefficient of variation = 0.27

is Residential, there is a certain advantage to predicting total land use using an aggregated predictive equation, as opposed to summing together the predicted levels of 12 individual predictive equations and a projection of the major project size. Although the coefficient of variation for the TOTUSE predictive equation in this case, 0.96, is slightly higher (more error) than the average coefficient of variation for the 12 predictive equations (see Table 3-3) of 0.91, the R^2_a value of 0.64 is also higher (more explained variance) than the 12 equation average of 0.55. For the Industrial/Office model, the advantages are more clearcut in using the TOTUSE predictive equation. The aggregated predictive equation coefficient of variation is only 0.27, compared to a 12 equation average of 0.83, and the R^2_a value is 0.80 compared to a 12 equation appropriate average of 0.53. Therefore, the use of the TOTUSE predictive equation is recommended whenever total land use projections are desired.

F. CROSS-VALIDATION ANALYSIS

The usefulness of any set of predictive equations depends upon their generality. Only if a regression equation is based upon a data sample which is representative of the general data population can it provide accurate predictions in different situations. In the current study, where only a small data sample (20) was available for the development predictive land use equations, the question of validity was especially important. The preferred test of an equation's validity is an external validation, viz., applying it on a test case basis to an independent sample of data (i.e., independent of the sample on which the coefficient values were based) and observing its predictive ability. In the current study a separate, independent sample was not available. Therefore, the analytical technique of cross-validation was used to simulate the existence of such a test sample.

The procedure of cross-validation involved splitting both the Residential and Industrial/Office data samples of 20 into two random samples of 10 each. In the Residential model, the first sample of 10 consisted of case numbers* 4,6,7,10,15,16,19,20,25, and 36; the second sample of 10

* See Table C-1 in the separately published Appendix C to Volume I [6] for a definition of case numbers.

consisted of case numbers 14,21,22,23,27,29,30,35,37 and 40. In the Industrial/Office model the first sample of 10 consisted of case numbers 1,2,3, 5, 9,11,12,13,26 and 34; the second sample of 10 consisted of case numbers 8,17,18,24,28,31,32,33,38 and 39. In each model, the coefficient values in the predictive equations were recomputed using the first data sample of 10 and the set of independent variables decided upon previously. These coefficient values, specifying 12 predictive equations in each model, were used in conjunction with the data for the independent variables from the second sample of 10 to predict the values of the dependent variables in the second sample of 10. Statistical comparisons were then made between actual and predicted values for the dependent variables in the second sample of 10.

Unlike the jackknifing technique used in the causal analysis to examine the stability of individual model coefficients, cross-validation provided a measure of the overall validity of the predictive equations.. The correlation coefficients (R) between actual and predicted values are shown in Table 3-7 and graphs of the actual versus fitted (predicted) values are summarized in Appendix B. In this application, the R statistic represents a coefficient of validity of the predictive ability of each equation. Values in Table 3-7 exceeding 0.63 are statistically significant at the five percent confidence level (two-tailed test). The results of the cross-validation indicate that about half of the 24 predictive equations are generalized enough to produce good predictions using an independent sample. The COMM, WHOLE, CHURCH, EDUC, and REC equations validated well in both models, as well as the RES and HWLMNX equations in the Industrial/Office model. Considering the extremely small sample size (10) used in the cross-validation and the large amounts of variance in the dependent variables, it was encouraging to obtain significant correlations between actual and predicted values in as many equations as we did.

Although coefficients of validity >0.63 indicate equations with good predictive ability, coefficients $\leq$ 0.63 do not necessarily indicate the associated predictive equation is useless. The poor correlations obtained

TABLE 3-7

COEFFICIENTS OF VALIDITY BETWEEN ACTUAL AND PREDICTED LAND USE FROM THE CROSS-VALIDATION ANALYSIS OF ALL LAND USE PREDICTIVE EQUATIONS

Independent Variable in Equation	Coefficient of Validity (R)	Statistical Significance Level
Residential Model		
RES	-0.11	--
COMM	0.85	0.005
OFFICE	0.07	--
MANF	0.43	--
HWLMNX	0.20	--
WHOLE	0.73	0.02
HOTEL	0.46	--
HOSPTL	0.44	--
CULTUR	0.35	--
CHURCH	0.69	0.05
EDUC	0.80	0.01
REC	0.74	0.02
Industrial/Office Model		
RES	0.81	0.005
COMM	0.77	0.001
OFFICE	-0.61	--
MANF	0.25	--
HWLMNX	0.71	0.05
WHOLE	0.86	0.005
HOTEL	0.46	--
HOSPTL	0.17	--
CULTUR	-0.12	--
CHURCH	0.62	0.10
EDUC	0.70	0.05
REC	0.67	0.05

could simply be due to nonhomogeneity in the data sample caused by the extremely small sample size (10). However, without an additional independent sample to use as a test case, it was not possible to ascertain if this was the case, or if the predictive equations simply lacked generality. In many instances where low R values were obtained, one or two particular samples consistently had the largest residuals (actual minus predicted), i.e., were outliers. It can be seen from the graphs of actual and fitted values (summarized in Appendix B) that in the Residential model, case number 30, and in the Industrial/Office model, case number 8, are recurrent outliers. Further work could be done in the validation analysis by assessing the effect of excluding certain outlier samples on the coefficients of validity obtained, and examining whether the actual values of such samples are indeed outliers in the dependent variable populations. Such efforts, however, were not attempted in the current study since it is quite probable that in a sample of only 10 that a single outlier may represent a valid 10 percent of the data population. Such possibilities, again, would be less likely if a larger sample were available for analysis. Further work could also be done in assessing the stability of the predicted land use estimates by computing overall confidence intervals for the predictive equations. All of the necessary data for computing confidence intervals is contained in Appendix A, which summarizes the statistical output for the predictive land use equations, including the variance - covariance matrices. Given an equation of the form:

$$Y = b_o + \sum_{i=1}^{n} b_i X_i$$

where:

Y is the dependent variable

$X_i, X_2, \ldots X_n$ are the independent variables

confidence intervals can be specified as:

$$Y \pm tV(Y)^{1/2}$$

where t is the t-statistic for the regression of the model equation and V(Y) is the variance of Y. V(Y) can be expressed as:

$$V(Y) = \sum_{i=1}^{n} \sum_{j=1}^{n} X_i X_j \text{ Covariance } (b_i b_j)$$

Worksheets for using the predictive equations and computing confidence intervals are given in Section VII.

IV. LAND USE BASED EMISSION FACTORS

This chapter discusses the approach used to develop the land use based emission factors and presents a tabular compilation of the emission factors that were developed. It is a summary of Volume II of the GEMLUP final report [7].

A. APPROACH TO LAND USE BASED EMISSION FACTORS

The objective of this phase of the GEMLUP study was to develop a set of land use based emission factors to permit the estimation of air pollutant emissions resulting from the construction and operation of a major land use project. These emission sources may be principally categorized as follows:

- Stationary source emissions occurring on the site of the major project (e.g., the on-site combustion of fuel oil for space heating needs),
- Stationary source emissions occurring at the land use induced by the major project (e.g., the on-site combustion of fuel oil for space heating needs),
- Secondary (i.e., occurring off-site) stationary source emissions (e.g., the combustion of fuel oil at the local electric utility to serve the electricity demand of the major project and induced land uses),
- Mobile source emissions (e.g., emissions due to motor vehicular traffic generated by the major project and induced land uses).

The latter category, mobile sources, is treated separately in Chapter VI of this report.

The estimation of emissions from the first three categories, all stationary sources, is the subject of this chapter. The means of this estimation is the use of land use based emission factors, that is, emissions per unit floor area of a particular land use category. Given the size of the major project and the amount of floor area, air pollutant emissions may then be estimated by taking the product of the appropriate land use based emission factor and the floor area of a particular land use category.

1. Emission Factor Structure

The land use based emission factors, emissions per unit floor area, may be disaggregated into two factors, an activity factor (i.e., fuel throughput, etc., per unit floor area), and the "Standard" emission factor (i.e., emissions per unit fuel). For example, in the case of fuel oil space heating consumption, this would be,

$$\frac{\text{emissions, gr.}}{\text{floor area, }10^3\text{ sq.ft.}} = \frac{\text{oil consumption, gals.}}{\text{floor area, }10^3\text{ sq.ft.}} * \frac{\text{emissions, gr.}}{\text{oil consumption, gals.}}$$

Given this structure, a complete set of land use based emission factors would consist of an n-dimensional array, with specific values given for a pollutant species, fuel or process type, building category, and, in some cases, energy requirements (e.g., region of the country).

Ignoring the solvent evaporation, solid waste disposal, and other miscellaneous emissions,* the energy consumption related emission factor can be generalized as follows:

$$\frac{\text{emissions}_{i,j,k}}{\text{sq.ft. year}} = \left[\left(\frac{\text{Btu}_i}{\text{sq.ft. year}} + \frac{\text{Btu}_i}{\text{sq.ft. ht.d.d.}} + \frac{\text{Btu}_i}{\text{sq.ft. cl.d.d.}}\right) * \frac{1}{\text{heat content}_i} * \frac{1}{\text{seasonal efficiency}_i} * \frac{\text{emissions}_j}{\text{unit fuel}_i}\right]_k$$

where ht.d.d. = heating degree days per year

cl.d.d. = cooling degree days per year

and for a particular fuel type i, pollutant species j, and building category k.

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*Emissions from these sources are not considered in this report, since there is both more limited information about their characteristics and that they may be expected to display more variation in per unit floor area emissions between parts of the country. However, the emission factor structure discussed above is amenable to their inclusion. It is recommended that they be included in areas where there are significant emission sources and/or better information concerning their characteristics is available.

The fourth term in this equation, emissions per unit fuel, are the commonly used values determined directly from the EPA Compilation of Air Pollutant Emission Factors [8]. Hence, the focus of this project is generating the first three terms (i.e., the activity factor).

The first three terms identify the fuel consumption per building floor area, given the heating and cooling degree days. The heat content of a fuel in British thermal units is approximately constant and is well known [9]. It does display some variation for every fuel, especially for natural gas in different regions of the country [10].

The values for the efficiency for various building types and fuels are less well known. Efficiency can be defined in a variety of ways. The purpose of this application is to account for the differences in the amount of energy consumed by a building depending on the fuel type selected to provide that energy.

The desired efficiency measure is the ratio of heat loss from a structure to the energy input to the structure, variously defined as efficiency of utilization or seasonal efficiency.

The term in brackets, the energy requirement per square foot and per square foot degree day, represents the energy requirements of a building. It is divided into three components:

- Process use of energy that is not related to climate; examples include:

  Lighting
  Elevators
  Refrigeration
  Water heating equipment
  Cooking equipment
  Ventilation

- Energy requirements for space heating, as a function of heating degree days*
- Energy requirements for air conditioning, as a function of cooling degree days.†

In lieu of cooling degree days for residential buildings, this study will use the estimated compressor operating hours of residential air conditioning units as compiled by Oak Ridge National Laboratory. A map of iso-compressor operating hours is shown in Figure 4-3.

2. Variance of Energy Requirement, Efficiency, and Emission Factors

The energy requirement factor, the efficiency of utilization, and the standard emission factors are all estimates of the mean of population values and can be expected to display a large variation. In general, these factors are not precise indicators of energy requirement, efficiency, or emissions of a single source. They are more valid when applied to a large number of sources.

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*Early this century, heating engineers developed the concept of heating degree days as a useful index of heating fuel requirements. They found that when the daily mean temperature is lower than 65 degrees, most buildings require heat to maintain an inside temperature of 70 degrees. The daily mean temperature is obtained by adding together the maximum and minimum temperature reported for the day and dividing the total by two. Each degree of mean temperature below 65 is counted as one heating degree day. Thus, if the maximum temperature is 70 degrees and the minimum 52 degrees, four heating degree days would be produced. (70 + 52 = 122, 122 divided by 2 = 61; 65 - 61 = 4). If the daily mean temperature is 65 degrees or higher, the heating degree day total is zero. A map of iso-heating degree days for the United States is shown in Figure 4-1 [11].

†The cooling degree day is a mirror image of the heating degree day. After obtaining the daily mean temperature by adding together the day's high and low temperatures and dividing the total by two, the base 65 is subtracted from the resulting figure to determine the cooling degree day total. For example, a day with a maximum temperature of 82 degrees and a minimum of 60 would produce six cooling degree days. (82 + 60 = 142; 142 divided by 2 = 71; 71 - 65 = 6). If the daily mean temperature is 65 degrees or lower, the cooling degree day total is zero [11].

Figure 4-1: NORMAL SEASONAL HEATING DEGREE DAYS (BASE 65°F) 1941–1970

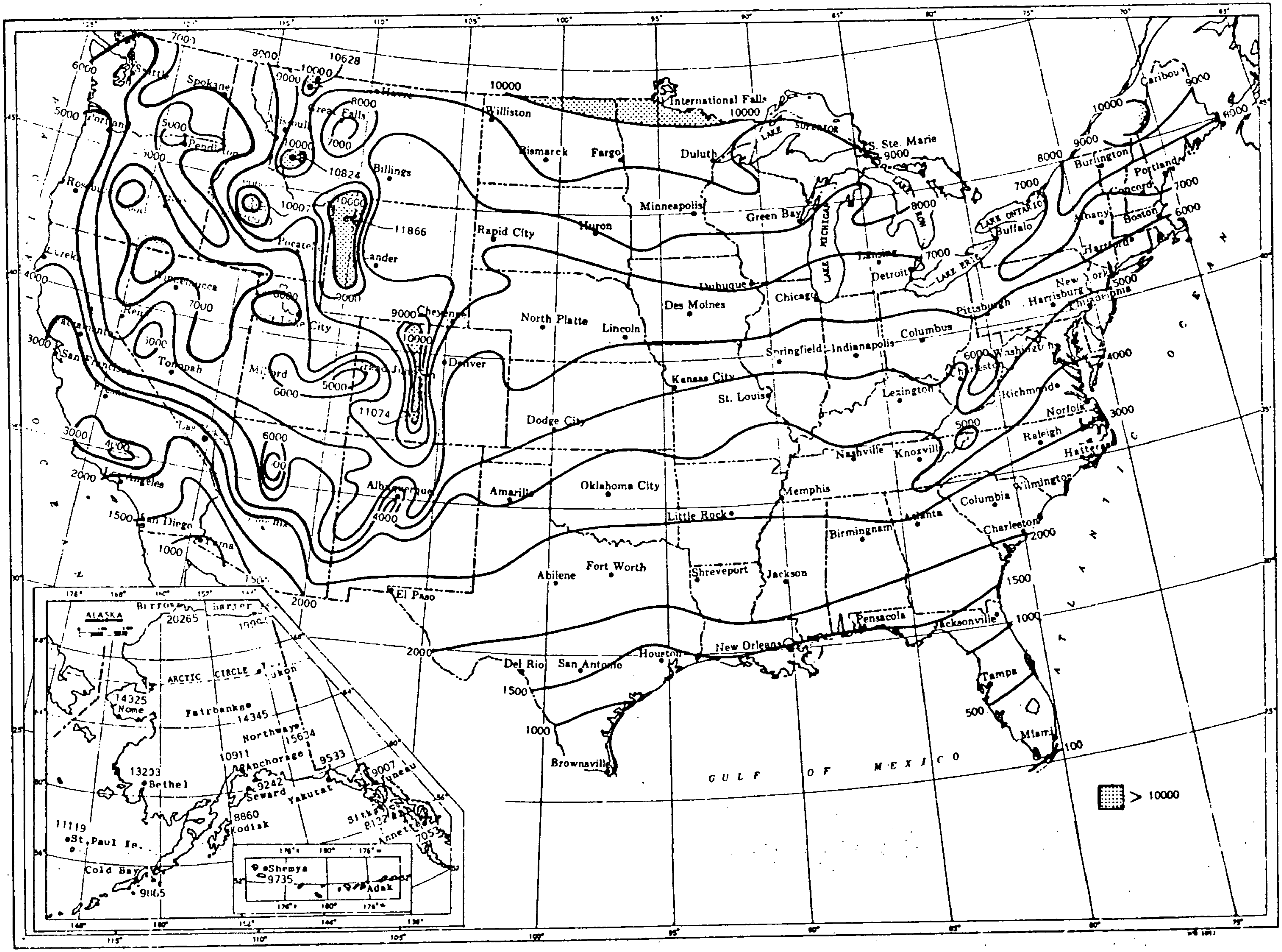

Figure 4-2: NORMAL SEASONAL COOLING DEGREE DAYS (BASE 65°F) 1941–1970

FIGURE 4-3. ANNUAL AIR CONDITIONER COMPRESSOR-OPERATING HOURS FOR HOMES THAT ARE NOT NATURALLY VENTILATED. Source: Oak Ridge National Laboratory [35].

B. COMPILATION OF LAND USE BASED EMISSION FACTORS

This section presents a tabular summary of the land use based emission factors. The emission factors are presented in units of pounds of pollutant emitted per "measure" for oil and gas combustion. For electricity consumption, the factors are in terms of kilowatt-hours per "measure". The measure, depending on the activity involved, may be per square foot of building floor area, per square foot heating degree day, per dwelling unit, etc.

The quantity of secondary, i.e., off-site, emissions occurring due to electricity consumption depends on the nature of the local electricity utility generating station. It is suggested that the local utility be contacted to determine the appropriate emission factor. Default values of pounds of pollutant emissions per kilowatt-hour sold are presented in Table 4-1 and are based on data in References 8, 12, and 13. It should also be pointed out that the emissions due to increased electrical demand do not necessarily occur at the nearest generating plant.

Tables 4-2 through 4-13 present the land use based emission factors for residential, commercial, institutional, and industrial land uses. The industrial factors do not include process emissions. Metric equivalents of these emission factors are given in Volume II of this report [7].

TABLE 4-1

TYPICAL UNCONTROLLED EMISSION FACTORS FOR ELECTRIC UTILITIES

	lbs. emissions per kWh sold to customer				
	PM	SO_x	CO	HC	NO_x
coal	$5.23 \times 10^{-3}A$	$1.53 \times 10^{-2}S$	4.03×10^{-4}	1.21×10^{-4}	2.21×10^{-2}
oil	6.34×10^{-4}	$1.26 \times 10^{-2}S$	2.38×10^{-4}	1.58×10^{-4}	8.32×10^{-3}
gas	1.19×10^{-4}	7.13×10^{-6}	2.02×10^{-4}	1.19×10^{-5}	8.32×10^{-3}

Note: A 33.3% overall plant efficiency is assumed for coal-fired plants [12].
A 31.6% overall plant efficiency is assumed for oil- and gas-fired plants [12].
A 10% transmission loss is assumed [13].
'S' and 'A' represent, respectively, the sulfur and ash percentage of fuel by weight.

TABLE 4-2

SINGLE FAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

	pound of pollutant (or kilowatt-hours) per measure						
	PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	3.8	dwelling unit·ht.d.d.
Gas	2.6×10^{-4}	1.5×10^{-5}	5.1×10^{-4}	2.0×10^{-4}	2.6×10^{-3}	-	dwelling unit·ht.d.d.
Oil	2.2×10^{-3}	$3.2 \times 10^{-2}S$	1.1×10^{-3}	6.6×10^{-4}	2.6×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	4.7	dwelling unit·op.hr.
Gas	1.8×10^{-4}	1.1×10^{-5}	3.5×10^{-4}	1.4×10^{-4}	1.8×10^{-3}	-	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	5.1×10^{-1}	a.c. unit·operating hour
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.4 \times 10^{+4}$	dwelling unit·year
Gas	3.0×10^{-1}	1.8×10^{-2}	6.0×10^{-1}	2.4×10^{-1}	3.0	-	dwelling unit·year
Oil	2.5	$3.7 \times 10^{-1}S$	1.2	7.5×10^{-1}	3.0	-	dwelling unit·year
Cooking							
Electricity	-		-	-	-	$3.5 \times 10^{+3}$	dwelling unit·year
Gas	1.1×10^{-1}	6.6×10^{-3}	2.2×10^{-1}	8.8×10^{-2}	1.1		dwelling unit·year
Miscellaneous	-	-	-	-	-	$7.9 \times 10^{+3}$	dwelling unit·year

Note: A 1600 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 4-3

MOBILE HOME RESIDENTIAL LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (or kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	2.32	dwelling unit·ht.d.d.
Gas	1.7×10^{-4}	9.9×10^{-6}	3.3×10^{-4}	1.3×10^{-4}	1.7×10^{-3}	-	dwelling unit·ht.d.d.
Oil	1.4×10^{-3}	$2.0 \times 10^{-2}S$	6.9×10^{-4}	4.2×10^{-4}	1.7×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	3.4	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	5.1×10^{-1}	a.c. unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.3 \times 10^{+4}$	dwelling unit·year
Gas	3.0×10^{-1}	1.8×10^{-2}	6.0×10^{-1}	2.4×10^{-1}	3.0	-	dwelling unit·year
Oil	2.5	$3.6 \times 10^{+1}S$	1.2	7.5×10^{-1}	3.0	-	dwelling unit·year
Cooking							
Electricity	-	-	-	-	-	$3.5 \times 10^{+3}$	dwelling unit·year
Gas	1.1×10^{-1}	6.6×10^{-3}	2.2×10^{-1}	8.8×10^{-2}	1.1	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$7.9 \times 10^{+3}$	dwelling unit·year

Note: A 720 square feet per dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 4-4

LOW RISE MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	1.3	dwelling unit·ht.d.d.
Gas	1.2×10^{-4}	7.3×10^{-6}	2.4×10^{-4}	9.7×10^{-5}	1.2×10^{-3}	-	dwelling unit·ht.d.d.
Oil	1.1×10^{-3}	$1.7 \times 10^{-2}S$	5.7×10^{-4}	3.4×10^{-4}	1.4×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	1.5	dwelling unit·op.hr.
Gas	6.2×10^{-5}	3.7×10^{-6}	1.2×10^{-4}	5.0×10^{-5}	6.2×10^{-4}	-	dwelling unit·op.hr.
Oil	4.5×10^{-4}	6.4×10^{-3}	2.2×10^{-4}	1.3×10^{-4}	5.3×10^{-4}	-	dwelling unit·op.hr.
Room							
Electricity	-		-	-	-	5.1×10^{-1}	a.c. unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$1.1 \times 10^{+4}$	dwelling unit·year
Gas	2.4×10^{-1}	1.4×10^{-2}	4.8×10^{-1}	1.9×10^{-1}	2.4	-	dwelling unit·year
Oil	2.0	$2.9 \times 10^{+1}S$	1.0	6.0×10^{-1}	2.4	-	dwelling unit·year
Cooking & Dryer							
Electricity	-	-	-	-	-	$3.8 \times 10^{+3}$	dwelling unit·year
Gas	1.2×10^{-1}	7.2×10^{-3}	2.4×10^{-1}	9.6×10^{-2}	1.2	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$4.4 \times 10^{+3}$	dwelling unit·year

Note: A 900 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 4-5

HIGH RISE MULTIFAMILY RESIDENTIAL LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure PM	SO_x	CO	HC	NO_x	kWh	Measure
Space Heating							
Electricity	-	-	-	-	-	1.5	dwelling unit·ht.d.d.
Gas	1.0×10^{-4}	6.2×10^{-6}	2.1×10^{-4}	8.3×10^{-5}	1.0×10^{-3}	-	dwelling unit·ht.d.d.
Oil	1.0×10^{-3}	$1.5 \times 10^{-2}S$	5.2×10^{-4}	3.1×10^{-4}	1.3×10^{-3}	-	dwelling unit·ht.d.d.
Air Conditioning							
Central							
Electricity	-	-	-	-	-	1.5	dwelling unit·op.hr.
Room							
Electricity	-	-	-	-	-	.51	dwelling unit·op.hr.
Process							
Hot Water							
Electricity	-	-	-	-	-	$6.2 \times 10^{+3}$	dwelling unit·year
Gas	1.4×10^{-1}	8.4×10^{-3}	2.8×10^{-1}	1.1×10^{-1}	1.4	-	dwelling unit·year
Oil	1.1	$1.6 \times 10^{+1}S$	5.7×10^{-1}	3.4×10^{-1}	1.4	-	dwelling unit·year
Cooking & Dryer							
Electricity	-		-	-	-	$3.8 \times 10^{+3}$	dwelling unit·year
Gas	1.2×10^{-1}	7.2×10^{-3}	2.4×10^{-1}	9.6×10^{-2}	1.2	-	dwelling unit·year
Miscellaneous	-	-	-	-	-	$5.9 \times 10^{+3}$	dwelling unit·year

Note: A 900 square foot dwelling unit is assumed.
'S' represents the sulfur percentage of oil, by weight.

TABLE 4-6

RETAIL ESTABLISHMENTS, WAREHOUSES, WHOLESALING ESTABLISHMENTS, LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (or kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	1.3×10^{-3}	sq.ft.• ht.d.d.
Gas	9.8×10^{-8}	5.9×10^{-9}	2.0×10^{-7}	7.8×10^{-8}	9.8×10^{-7}	-	sq.ft.• ht.d.d.
Oil	1.7×10^{-6}	$1.2 \times 10^{-5}S$	2.9×10^{-7}	3.3×10^{-5}	4.4×10^{-6}	-	sq.ft.• ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.2×10^{-3}	sq.ft.• cl.d.d.
Process							
Hot Water							
Electricity	-	-	-	-	-	5.0×10^{-1}	sq.ft.• year
Gas	2.4×10^{-5}	1.4×10^{-6}	4.8×10^{-5}	1.9×10^{-5}	2.4×10^{-4}	-	sq.ft.• year
Oil	5.2×10^{-4}	$3.6 \times 10^{-3}S$	9.1×10^{-5}	1.0×10^{-2}	1.4×10^{-3}	-	sq.ft.• year
Lighting	-	-	-	-	-	8.0	sq.ft.• year
Auxiliary Equipment	-	-	-	-	-	3.6	sq.ft.• year
Appliances	-	-	-	-	-	2.0	sq.ft.• year
Refrigeration	-	-	-	-	-	8.9	sq.ft.• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-7

OFFICE BUILDING LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (or kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	1.9×10^{-3}	sq.ft.•ht.d.d.
Gas	9.4×10^{-8}	5.6×10^{-9}	1.9×10^{-7}	7.5×10^{-8}	9.4×10^{-7}	-	sq.ft.•ht.d.d.
Oil	1.7×10^{-6}	$1.2 \times 10^{-5}S$	2.9×10^{-7}	3.3×10^{-5}	4.4×10^{-6}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	1.5×10^{-3}	sq.ft.•cl.d.d.
Gas	7.4×10^{-8}	4.4×10^{-9}	1.5×10^{-7}	5.9×10^{-8}	7.4×10^{-7}	-	sq.ft.•cl.d.d.
Oil	1.3×10^{-6}	$9.1 \times 10^{-6}S$	2.3×10^{-7}	2.6×10^{-5}	3.4×10^{-6}	-	sq.ft.•cl.d.d.
Process	-	-	-	-	-	$2.8 \times 10^{+1}$	sq.ft.•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-8

NONHOUSEKEEPING* RESIDENTIAL LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						Measure
	PM	SO_x	CO	HC	NO_x	kWh	
Space Heating							
Electricity	-	-	-	-	-	1.7×10^{-3}	sq.ft.•ht.d.d.
Gas	9.4×10^{-8}	5.6×10^{-9}	1.9×10^{-7}	7.5×10^{-8}	9.4×10^{-7}	-	sq.ft.•ht.d.d.
Oil	1.4×10^{-6}	$9.9 \times 10^{-6}S$	2.5×10^{-7}	2.8×10^{-5}	2.8×10^{-5}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	4.7×10^{-4}	sq.ft.•cl.d.d.
Gas	2.3×10^{-8}	1.4×10^{-9}	4.6×10^{-8}	1.8×10^{-8}	2.3×10^{-7}	-	sq.ft.•cl.d.d.
Oil	4.1×10^{-7}	$2.8 \times 10^{-6}S$	7.1×10^{-8}	8.0×10^{-6}	1.1×10^{-6}	-	sq.ft.•cl.d.d.
Process	-	-	-	-	-	$1.2 \times 10^{+1}$	sq.ft.•year

* Hotels, Motels, Dormatories, etc.

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-9

HOSPITAL LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						Measure
	PM	SO_x	CO	HC	NO_x	kWh	
Space Heating							
Electricity	-	-	-	-	-	2.2×10^{-3}	sq.ft.•ht.d.d.
Gas	1.8×10^{-7}	1.1×10^{-8}	3.7×10^{-7}	1.5×10^{-7}	1.8×10^{-6}	-	sq.ft.•ht.d.d.
Oil	3.3×10^{-6}	$2.3 \times 10^{-5}S$	5.8×10^{-7}	6.6×10^{-5}	8.7×10^{-6}	-	sq.ft.•ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.9×10^{-3}	sq.ft.•cl.d.d.
Process							
Lighting	-	-	-	-	-	$1.5 \times 10^{+1}$	sq.ft•year
Auxiliary Equipment	-	-	-	-	-	$1.7 \times 10^{+1}$	sq.ft•year
Appliances	-	-	-	-	-	5.9	sq.ft.•year
Hot Water							
Electricity	-	-	-	-	-	5.0	sq.ft.•year
Gas	2.4×10^{-4}	1.4×10^{-5}	4.8×10^{-4}	1.9×10^{-4}	2.4×10^{-3}	-	sq.ft.•year
Oil	5.2×10^{-3}	$3.6 \times 10^{-2}S$	9.1×10^{-4}	1.0×10^{-1}	1.4×10^{-2}	-	sq.ft.•year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-10

CULTURAL BUILDING LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (or kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	1.8×10^{-3}	sq.ft.·ht.d.d.
Gas	9.0×10^{-8}	5.4×10^{-9}	1.8×10^{-7}	7.2×10^{-8}	9.0×10^{-7}	-	sq.ft.·ht.d.d.
Oil	1.6×10^{-6}	$1.1 \times 10^{-5}S$	2.8×10^{-7}	3.2×10^{-5}	4.2×10^{-6}	-	sq.ft.·ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	5.9×10^{-4}	sq.ft.·cl.d.d.
Gas	2.9×10^{-8}	1.7×10^{-9}	5.7×10^{-8}	2.3×10^{-8}	2.9×10^{-7}	-	sq.ft.·cl.d.d.
Oil	5.1×10^{-7}	$3.6 \times 10^{-6}S$	8.9×10^{-8}	1.0×10^{-5}	1.3×10^{-6}	-	sq.ft.·cl.d.d.
Process	-	-	-	-	-	$1.2 \times 10^{+1}$	sq.ft.·year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-11

CHURCH BUILDING LAND USE BASED EMISSION FACTORS

Activity	pound of pollutant (or kilowatt-hours) per measure						Measure
	PM	SO_x	CO	HC	NO_x	kWh	
Space Heating							
Electricity	-	-	-	-	-	2.9×10^{-3}	sq.ft.·ht.d.d.
Gas	1.4×10^{-7}	8.6×10^{-9}	2.9×10^{-7}	1.1×10^{-7}	1.4×10^{-6}	-	sq.ft.·ht.d.d.
Oil	2.6×10^{-6}	$1.8 \times 10^{-5}S$	4.5×10^{-7}	5.0×10^{-5}	6.7×10^{-6}	-	sq.ft.·ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	3.8×10^{-3}	sq.ft.·cl.d.d.
Gas	1.8×10^{-7}	1.1×10^{-8}	3.7×10^{-7}	1.5×10^{-7}	1.8×10^{-6}	-	sq.ft.·cl.d.d.
Oil	3.3×10^{-6}	$2.3 \times 10^{-5}S$	5.7×10^{-7}	6.4×10^{-5}	8.6×10^{-6}	-	sq.ft.·cl.d.d.
Process	-	-	-	-	-	4.2	sq.ft.·year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-12

SCHOOL BUILDING LAND USE BASED EMISSION FACTORS

Activity	PM	SO_x	CO	HC	NO_x	kWh	Measure
	pound of pollutant (or kilowatt-hours) per measure						
Space Heating							
Electricity	-	-	-	-	-	1.7×10^{-3}	sq.ft.• ht.d.d.
Gas	8.0×10^{-8}	4.8×10^{-9}	1.6×10^{-7}	6.4×10^{-8}	8.0×10^{-7}	-	sq.ft.• ht.d.d.
Oil	1.2×10^{-6}	8.5×10^{-6}	2.1×10^{-7}	2.4×10^{-5}	3.2×10^{-6}	-	sq.ft.• ht.d.d.
Air Conditioning							
Electricity	-	-	-	-	-	4.7×10^{-4}	sq.ft.• cl.d.d.
Gas	2.3×10^{-8}	1.4×10^{-9}	4.6×10^{-8}	1.8×10^{-8}	2.3×10^{-7}	-	sq.ft.• cl.d.d.
Oil	4.1×10^{-7}	2.8×10^{-6}	7.1×10^{-8}	8.0×10^{-6}	1.1×10^{-6}	-	sq.ft.• cl.d.d.
Process	-	-	-	-	-	7.1	sq.ft.• year

Note: 'S' represents the sulfur percentage of oil, by weight.

TABLE 4-13

ESTIMATED NATIONAL INDUSTRIAL LAND USE BASED EMISSION FACTORS BY TWO DIGIT 1967 STANDARD INDUSTRIAL CLASSIFICATION CODE

	pounds of pollutant (or kWh of electricity) per floor area sq.ft.•year					
SIC Code	PM	SO_x	CO	HC	NO_x	J
20	.64	.50	.013	.0033	.13	38
21	1.22	1.02	.025	.014	.23	48
22	.58	.54	.014	.0081	.14	68
23	.06	.04	.0014	.00084	.015	16
24	.06	.07	.0034	.0023	.045	22
25	.11	.08	.0022	.0012	.021	14
26	3.12	3.09	.069	.040	.69	85
27	.01	.02	.00068	.00048	.0095	25
28	.10	.46	.011	.0081	.16	181
29	1.06	2.78	.055	.038	.73	426
30	.51	.38	.010	.0058	.097	50
31	.17	.17	.0047	.0029	.052	18
32	4.03	2.67	.72	.038	.61	78
33	3.06	2.38	.061	.034	.57	297
34	.14	.12	.0035	.0021	.036	33
35	.22	.18	.0047	.0027	.046	31
36	.22	.20	.0053	.0032	.056	56
37	.68	.48	.013	.0068	.11	54
38	.95	.70	.018	.0095	.15	38
19 & 39	.08	.13	.0035	.0024	.044	31

Note: The following is assumed:
2% sulfur in coal
10% ash in coal

0.2% sulfur in distillate oil
1.75% sulfur in residual oil

1967 SIC codes are used because of data availability. The 1972 SIC code manual provides conversions between 1967 and 1972 codes [14].

V. THE TRAFFIC MODEL

A. INTRODUCTION

This chapter discusses the vehicle miles traveled (VMT) submodel of the GEMLUP methodologies for predicting air pollutant emissions from the construction and operation of a major land use project and its induced land uses. The VMT submodel predicts the vehicle miles traveled from either an absolute amount of land use in the 10,000 acre area of influence or from an amount of change in land use in the area of influence. The input to the VMT submodel is therefore, either,

- The absolute amount of development in the 10,000 acre area of influence, obtained by suming the output of the predictive equations of the land use submodel and the projected size of the major project, or
- The change in development in the area of influence, either between two major project configurations or between the projected land use at the end of ten years and the base case.

The elements of the VMT model include vehicle trip generation rates for the several categories of land use, the corresponding trip lengths, the VMT traveled by vehicles in several categories, the VMT traveled in several speed ranges, and the VMT occurring only within the study area.

The precedents for this kind of model were found to be limited. Generally, this is because most land use transportation studies are based on the interaction of relatively large segments of regional or metropolitan areas. In the current study, the character and quantity of the several land uses are likely to be unique for each study area. Nevertheless, the location of a given land area in a metropolitan area is a geographic specification of distance relationships that are also principal determinants of several factors affecting VMT. Among these are distances to the metropolitan core and other major centers of development, and orientation to principal transportation elements such as expressways, transit terminals, and airports. As a result, the regional transportation planning agency is a valuable potential source for some of the model's variables. In this vein, it is considered desirable to use local sources of information when available.

B. SUMMARY

Vehicle miles traveled are computed for an "impact area" which is defined to include both the VMT occurring within the 10,000 acre area of influence as well as VMT outside the area of influence but occurring because of the presence of the major project and its induced land uses.

Total vehicle miles traveled in the impact area (denoted VMT^I), is computed as a product of vehicle trips and trip lengths, corrected for a duplication of trips, viz.,

$$VMT^I = [\sum_{i=1}^{2} \sum_{j=1}^{17} LU_j \, L_i \, T_{i,j}] - L_r \, (\sum_{j=1}^{6} LU_j \, T_{2,j})F$$

and VMT in the area of influence is computed as follows,

$$VMT^A = L_r \, [\sum_{i=1}^{2} \sum_{j=1}^{17} LU_j \, T_{i,j}] - L_r \, (\sum_{j=1}^{6} LU_j \, T_{2,j})F$$

LU_j = Amount of land use (number of dwelling units or thousands of square feet of building floor area) where j is defined as,

1 = Residential Single family detached
2 = Residential Single family attached
3 = Residential Multifamily lowrise
4 = Residential Multifamily highrise
5 = Residential Mobile home
6 = Residential, Nonhousekeeping (Hotels, Motels, etc.)
7 = Commercial <50,000 ft^2 (COMM1)
8 = Commercial 50,000-100,000 ft^2 (COMM2)
9 = Commercial >50,000 ft^2 (COMM3)
10 = Office (OFFICE)
11 = Manufacturing (MANF)
12 = Wholesale & Warehousing (WHOLE)

13 = Cultural (CULTUR)
14 = Church (CHURCH)
15 = Hospitals (HOSPTL)
16 = Educational (EDUC)
17 = Recreation (REC)

L_i = Trip length (miles), where i is defined as

L_i = Work oriented tmp length
L_2 = "Other trip" length
L_r = Study area radius

T_i = Trip generation rate (vehicles per day), where i is defined as:
T_1 = Work-trip generation rate
T_2 = "Other" trip generation rate

F = Fraction of home based "Other" trips with an $L_2 < L_r$

The total VMT in both cases (i.e., impact area and area of influence) are then divided into four vehicle classes. These classes are gasoline, automobiles, light duty gasoline trucks, heavy-duty gasoline trucks, and heavy-duty diesel vehicles. The fractionation is computed as a function of the mix of land use categories in the area of influence.

The total VMT in both cases are also divided into three facility classes, viz., local streets, arterial streets, and expressways. The proportion of the VMT occurring on each facility type is a function of the estimated trip length, L_i and L_2, for work and other trips. Finally, the average route speed of VMT on each facility type is estimated to permit the calculation of air pollutant emissions from motor vehicles.

The significance and characteristics of the factors in the model are presented in the following section. Procedures for applying the model are presented in Chapter VII. An example of the application of the model is shown in Chapter VIII.

C. PRINCIPAL ELEMENTS OF THE VMT MODEL

1. Introduction

This study is concerned, in part, with the air quality impacts of changes in mobile sources, occurring from predicted changes in mobile sources, accruing from predicted changes in land use within a 10,000-acre study area. VMT, categorized in appropriate vehicle classes and route speeds, is the appropriate data base for calculation of air pollutant emissions from mobile sources. The VMT should be conceived of as an "overlay" to the regional condition. Thus, whereas vehicular travel through the area is not evaluated, all the principal elements of VMT generated by the land uses within the study area are calculated.

The time at which the VMT estimate is to be made is important. Factors such as trip generation and trip length may be affected by time. These factors will be discussed individually in following paragraphs. In respect to time, however, care should be taken in viewing the study area in the perspective of comparison with similar land uses and related factors for which current data exists.

The output of the predictive land use model is the primary input for the VMT model. These data are to be abstracted in the form of the number of housing units and the thousands of square feet or acres of the land use categories. The types of residence are measured in numbers of dwelling units; all other land uses are measured in thousands of square feet of building except for land devoted to active recreation, which is measured in acres.

2. Vehicle Trip Generation Rates

A trip in the traffic submodel is defined as a one-way vehicle movement with either the origin or the destination inside the area of influence. A trip generation rate is the 24-hour estimate of vehicle trips to and from a unit of land use (e.g., trips per dwelling unit, trips per thousand square feet of floor area, and trips per acre of land use). Vehicle trips are defined in terms of trip purpose. In the GEMLUP traffic model, only two categories are used, "work" trips and non-work related "other" trips.

Trip rates will vary with such factors as geographical location within a metropolitan area, distance from the core, auto ownership, density, etc. For example, it is generally believed that auto ownership and income can be used to estimate trip generation rates for residence area. For example, Table 5-1 shows characteristic relationships for a large regional area. The variability of trip rates for other land uses is less defined. For example, Levinson [15] tabulates the following ranges and typical values for retail-commercial land use vehicle trip generation rates:

Land Use Retail Commercial	Vehicle Trip Generation Rate 10^3 Square Feet	
	Range	Typical
Neighborhood Retail	70-240	130
Community Retail	60-140	80
Regional Retail	30-50	40
Central Area Retail	10-50	40

As default values for use in the model, a compilation of trip generation rates for land use categories have been prepared based on references [15,16,17]. These rates are tabulated in Table 5-2. However, it is believed that superior results will be obtained by considering locally available data before selecting trip generation rates. Regional transportation planning projects in many areas have produced and tabulated similar data that may be more appropriate.

The values contained in Table 5-2, though they correspond generally to those contained in one or more of the references, have been adapted so as to reflect the categories of land use that are aggregated in

TABLE 5-1

EFFECT OF CAR OWNERSHIP ON AVERAGE NUMBER OF TRIPS PER HOUSEHOLD BY TRIP PURPOSE, CINCINNATI URBANIZED AREA

Trip Purpose	Noncar Households	One-car Households	Multicar Households	Ratio One/None	Ratio Multi/One
Home-based Work	.62	1.66	2.49	2.68	1.50
Home-based Shopping	.37	1.05	1.58	2.84	1.50
Home-based Social-Rec.	.30	1.11	2.10	3.70	1.89
Home-based School*	.17	0.44	1.04	2.59	2.36
Home-based other	.32	0.87	1.58	2.71	1.81
Nonhome-based	.19	1.37	2.86	7.20	2.09
All Purposes	1.97	6.50	11.65	3.30	1.79

* Based on trip and household data from households interviewed during school year.

Source: "Urban Transportation Models", Ohio-Kentucky-Indiana Regional Transportation and Development Plan, Wilbur Smith and Associates, 1972.

TABLE 5-2

DEFAULT VEHICLE TRIP GENERATION RATIOS FOR VARIOUS LAND USE CATEGORIES

Land Use Type	Trips per measure	Work Trips, T_1		Other Trips, T_2	
		Range	Typical	Range	Typical
single family detached	dwelling units	1.0-2.5	1.8	6-13	9
single family attached	dwelling units	0.8-2.2	1.5	5-11	7
multifamily low rise	dwelling units	0.6-1.8	1.2	4-8	6
multifamily high rise	dwelling units	0.3-0.8	0.8	2-7	4
mobile homes	dwelling units	1.5-2.0	1.8	4-7	5
hotels, motels	10^3 sq. feet	0.3-0.5	0.4	4-12	10
	sq. meters	.003-.01	.004	.04-.13	.11
commercial 1	10^3 sq. feet	0	0	70-240	130
	sq. meters			.75-2.58	1.4
commercial 2	10^3 sq. feet	0	0	60-140	80
	sq. meters			.65-1.51	.86
commercial 3	10^3 sq. feet	0	0	30-50	40
	sq. meters			.32-.54	.43
office	10^3 sq. feet	6.60	16	0	0
	sq. meters	.06-.65	.17		
manufacturing	10^3 sq. feet	.5-6	5	0	0
	sq. meters	.01-.06	.05		
wholesale/warehousing	10^3 sq. feet	.5-5.5	4	0	0
	sq. meters	.01-.06	.04		
cultural	10^3 sq. feet	0	0	1-4	2
	sq. meters			.01-.04	.02
churches	10^3 sq. feet	0	0	1-4	2
	sq. meters			.01-.04	.02
hospitals	10^3 sq. feet	5-35	16	0	0
	sq. meters	.05-.38	.17		
educational	10^3 sq. feet	0	0	1-5	4
	sq. meters			.01-.05	.04
recreation	acres	0	0	8-30	10
	sq. meters			32375-121407	40469

the individual classifications in the output of the GEMLUP land use model. In most instances, ranges and typical values have been adjusted based on our judgment.

The vehicle trip generation rates in Table 5-2 assume a generally low level of mass transit usage. In general, this is an acceptable assumption. For example, the Washington Council of Governments [18] reported the following distribution of vehicle trips by vehicle type:

automobile	90.9%
truck	7.6%
public transit	0.6%
taxi	0.9%

In situations where the use of public transit is more predominent, the vehicle trip generation rates would require adjustment downward.

The accuracy of the traffic sub-model is more closely tied to estimation of numbers of vehicle trips than to any of the other variables. Considerations of the nature of the study area, its location with respect to the regional core, its mix of land uses, its population, etc., should precede selection of trip generation rates. No fixed logic pattern can be cited. Any unusual situations would require the use of local data and possibly the services of a transportation specialist.

3. Trip Lengths

The location of the study area within the metropolitan area affects vehicular trip lengths greatly. Core-oriented work trips are obviously affected, but so are other trips. For example, suburban residents drive farther as a rule for shopping, social and recreational, and other purposes than do residents in denser areas nearer the core.

Only two categories of trip lengths are used in the model. These are average lengths for work trips, L_1, and other trip purposes, L_2. Even though significant variations exist in lengths of other trip purposes, these two groups are consistent with the level of accuracy obtainable with the model. Again, it is desirable to make use of data available from metropolitan area planning processes. There are two alternatives for estimating the mean trip lengths, viz.,

- Obtain values from the regional transportation planning agency data. It is desirable to consider generalized location (distance from central city) and land use characteristics.
- Average vehicle trip lengths, L_1 and L_2, both generally have a high correlation with the distance from the metropolitan core. Table 5-3 is an example of data that might be available from a regional transportation planning agency. The ring system is defined on a map of the region shown in Figure 5-1. To select trip lengths, one would first locate the study area, and then would determine the ring designation. Depending on the year of development and the year upon which the data is based, the ring used for the estimate may be one ring closer to the core than the actual location otherwise would indicate. Thus, for a Ring 6 location and a 1985 estimate, an appropriate selection might be L_1 - 9.2 miles and L_2 = 5.5 miles, based on the given data.
- Alternatively one can solve the following equations:

$$L_1 = 0.003 * P^{0.20} * S_1^{1.49}$$

$$L_2 = 1/2\ (0.003 * P^{0.18} * S_2^{1.40} + 0.003 * P^{0.26} * S_2^{1.25})$$

where P = The SMSA population and

$S_{1,2}$ = The average network vehicle travel speed in miles per hour

These regression equations are presented in Reference 6. These formulas resulted from regression analyses of data from a number of U.S. cities ranging in population from 33,000 to 6,489,000 [19].

The value for the population that should be used in that of the Standard Metropolitan Statistical Area (SMSA). The value should be a prediction of the SMSA population for the year the traffic submodel is being used for. The value for $S_{1,2}$ may be that available from area transportation planning data or that selected from the following relationships.

TABLE 5-3

AVERAGE TRIP DISTANCES AND AUTOMOBILE TRAVEL BY RESIDENCE LOCATION - 1968

Residence Location (Ring)	Average Auto Trip Distance			Average Daily Miles Per Resident Automobile	Percent of Households Owning Cars	Average Daily Miles Per Household[1]		
	Home to Work	Home to Non-Work	Non-Home Based			Work	Non-Work	TOTAL
0	6.1	3.3	2.0	9.0	26	1.5	2.2	3.7
1	4.5	4.2	4.4	8.6	43	1.8	4.3	6.1
2	4.8	3.8	4.0	9.6	59	3.4	5.5	8.9
3	6.3	4.2	4.5	13.0	72	6.3	9.0	15.3
4	7.5	4.4	4.8	15.6	92	10.5	16.8	27.3
5	9.2	5.4	5.6	18.2	97	15.1	21.9	37.0
6	10.1	6.3	5.7	19.0	97	15.4	24.4	39.8
7	14.5	7.1	5.8	24.2	96	22.0	23.7	45.7
ALL	8.0	4.9	5.0	15.9	81	9.6	14.4	24.0

*Abstracted from Information Report No. 60, Table IV, WCOG, 1973.

[1]Averages include both car-owning and non-car owning households.

FIGURE 5-1 EXISTING ANALYSIS RINGS, WASHINGTON METROPOLITAN REGION

MPH	Road Networks Description
$S_{1,2} = 20$	Dense urban network or networks with poor arterial spacing (>1 mile) and few or remote expressways.
$S_{1,2} = 25$	Intermediate network between suburbs and core, fair arterials, some expressway service with fair access.
$S_{1,2} = 30$	Suburban networks; medium to good arterials good expressway access.
$S_{1,2} = 35$	Open network with good to excellent arterial and/or expressways with good access.

The value for L_r, required for trip lengths for VMT only within the study area, is usually 2.23 miles. If the study area is non-circular because of its location and the local geography, a local effective L_r will need to be estimated.

4. Duplicated Trips

Because of the size of the study area and the nature of trip generation rates, there is a duplication of estimated trips within the area of influence. The source of this duplication is the double counting that occurs when both ends of a trip are within the area of influence. The dwelling unit (shopping) trip and the commercial (shopping) trip is an example.

The procedure for obtaining a correction for duplicated trips is based on the premise that the majority of such trips are home to work or home based other trips. Duplicated trips between dwelling units or between non-residential trip generators are assumed to be negligible. The correction factor is, therefore, the proportion of home to work and home based other trips that have a trip length less than the radius of the area of influence L_r.

If trip length distribution curves are available from regional transportation data, this fraction may be selected directly. A typical curve of the type that may be obtained is shown in Figure 5-2.

If such curves or specific values are not available, the factor may be assumed to be 0.40. A number of locations, such as that shown in Figure 5-2, were determined to have slightly higher values. The value of 0.40 was selected as a conservative correction factor (i.e., the higher a porportion that is used, the greater will be the number of trips that are subtracted as duplicated trips).

5. Speed Ranges

The relationship between vehicle average route speed and air pollutant emission rates (i.e., in grams per mile) make it critical to consider the average route speeds of the estimated VMT in calculating emissions. The emission factors presented in the EPA Compilation of Emission Factors [8], are estimated from a typical driving cycle that includes acceleration, deceleration, and constant operating speeds. Therefore, it is appropriate to only consider the average route speed.

The first step in determining the average speeds of the estimated VMT is to estimate the proportion of travel on various facilities. Most trips include distances and periods of time that are traveled on local streets, arterials, and expressways. It is recommended that through the use of a local highway network map and the consideration of the major trip generators in the study area, the proportion of time spent on each type of facility be estimated for a specific application of the model. In lieu of the procedure (e.g., where the highway network is unknown) the proportion of time spent on each type of facility can be estimated using a theoretical distribution. These graphs show the theoretical use of each facility given a freeway access ramp spacing (viz., two or four miles). The local streets and arterial streets are assumed to be distributed, respectively, every 0.125 and 1.0 mile. The freeways are spaced every two or four miles. Figures 5-3 and 5-4 show the

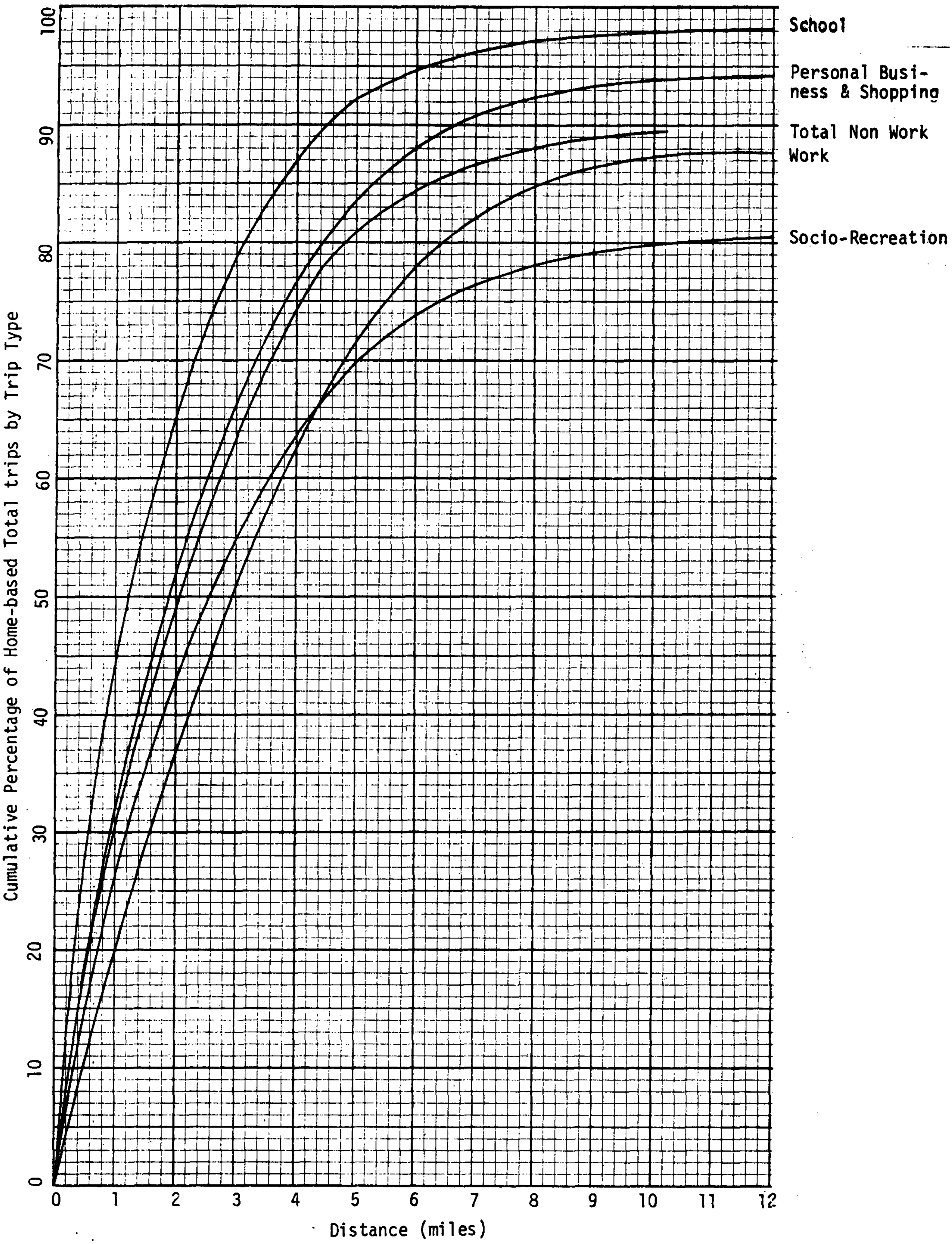

FIGURE 5-2 PLOT OF AVERAGE TRIP LENGTH FREQUENCY DISTRIBUTION BY TRIP TYPE

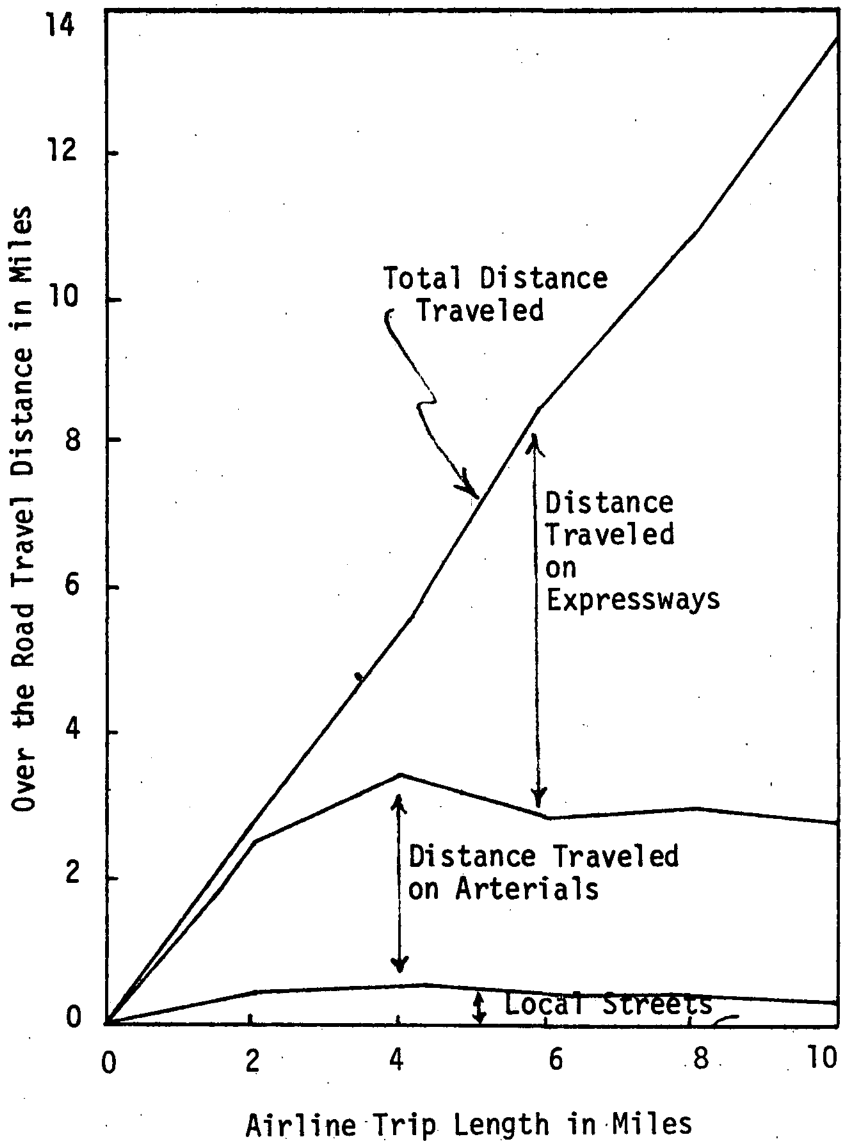

FIGURE 5-3 THEORETICAL RELATIVE USE OF LOCAL STREETS, ARTERIAL STREETS, AND EXPRESSWAYS WITH A TWO MILE RAMP SPACING

SOURCE: [20]

relative proportion of travel on each of the three types of facilities [20]. Using the previously calculated average trip lengths for work and other trips, the relative proportion of trips on each facility can be estimated. The airline trip distance is ignored. If it is not certain which figure is most applicable, it is suggested that the mean of the two figures be employed. For example, a hypothetical eight mile work trip length and five mile other trip length would result in the following calculation:

	Distance Traveled on Each Facility Type T_i (8 miles)				T_2 (5 miles)			
	2 mile spacing	4 mile spacing	mean	proportion	2 mile spacing	4 mile spacing	mean	proportion
local	0.5	0.5	0.5	.06	0.5	0.5	0.5	.10
arterial	2.5	3.5	3.0	.38	2.75	3.0	2.875	.575
expressway	5.0	4.0	4.5	.56	1.75	1.5	1.625	.325
			8	1.00			5	1.00

The proportion of distance traveled on each facility type (i.e., .06, .38, .56, .10, .575, .375) would then be employed (i.e., they should be entered on work sheet number (VMT-3)).

The calculation of VMT occurring in the area of influence had an assumed trip length of L_r (usually 2.23 miles). However, many of these trips are longer than L_r; all that the calculation attempts to estimate is that portion of the trip occurring within the area of influence. Therefore, rather than entering Figures 5-3 and 5-4 and calculating a new set of proportions of travel on each facility type, it is appropriate to use the proportions calculated in the preceeding paragraph.

While it is conceivable that the average route speed of <u>all</u> travel on each facility type could now be estimated, it is more accurate to consider the slower average route speed of VMT that occur during the peak

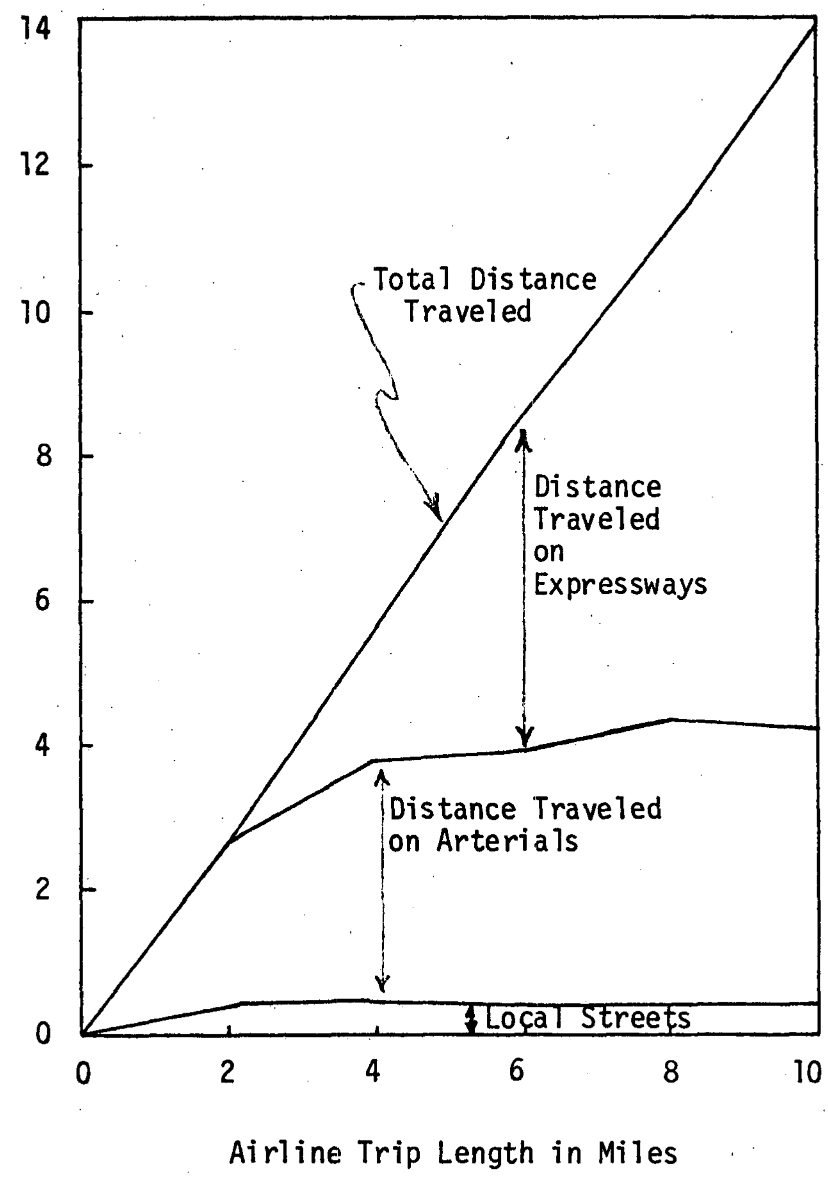

FIGURE 5-4 THEORETICAL RELATIVE USE OF LOCAL STREETS, ARTERIAL STREETS, AND EXPRESSWAYS WITH A FOUR MILE RAMP SPACING

SOURCE [20]

hour (i.e., rush hour). Approximately 10 percent of the average annual daily traffic will occur in the thirtieth highest peak hour [21]. The average route speeds of the 10% of VMT occurring during the peak hour* are then calculated separately from the 90% of VMT that is off peak.†

The average operating speed of each facility type is a function of the highway design speed and the ratio between the volume demand and the capacity. These relationships are depicted in Figures 5-5 and 5-6 for, respectively, expressways and urban arterials. If the typical volume-capacity ratio and design speed for the network under consideration is known, the average operating speed can be estimated. In lieu of obtaining this information, it is suggested that "C" level of service for off peak hour and "E" level of service for peak hour be used as conservative approximations. Accordingly, the following estimates can be made:

	off peak	peak
expressway	45	37
arterial 35 mph speed	28	20
local 25 mph speed	18	15

These values should be employed unless better estimates, based on local volume-capacity ratios and design speeds, are available.

6. <u>Vehicle Class</u>

In view of available emission factors, four classes of vehicles are used:

AG = gasoline powered automobiles

LDG = light-duty, gasoline powered trucks, ≤ 6,000 pounds, gross

HDG = heavy-duty, gasoline powered vehicles, > 6,000 pounds, gross vehicle weight

HDD = Diesel-powered vehicles (predominantly trucks and buses)

* Work trips are assumed to be of equal length, L_1 (other trips are also assumed to be of equal length, L_2).

† Vehicle speed during the afternoon peak hour is typically not substantially reduced.

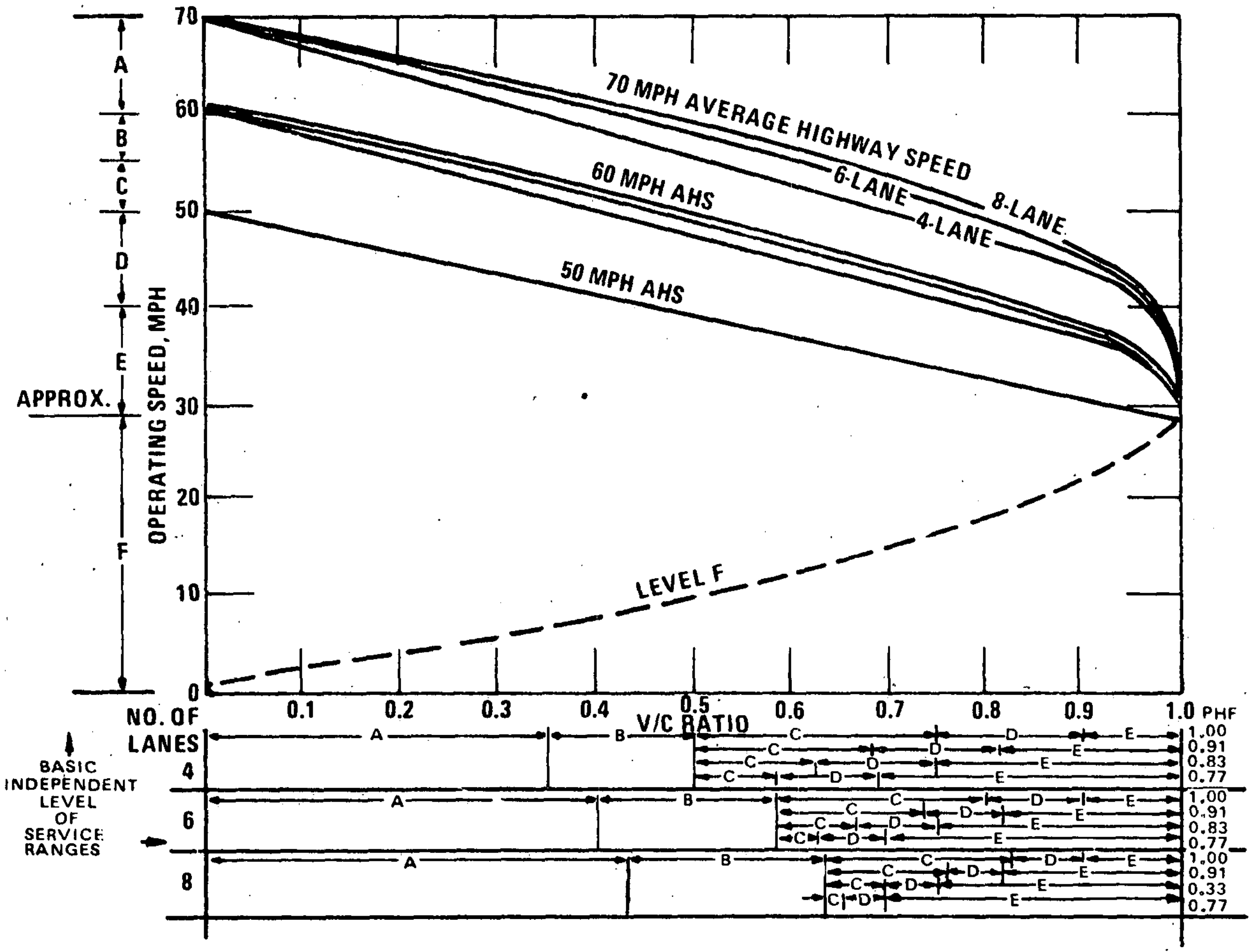

FIGURE 5-5 RELATIONSHIPS BETWEEN V/C RATIO AND OPERATING SPEED, IN ONE DIRECTION OF TRAVEL, ON FREEWAYS AND EXPRESSWAYS, UNDER UNINTERRUPTED FLOW CONDITIONS

SOURCE: REFERENCE [22].

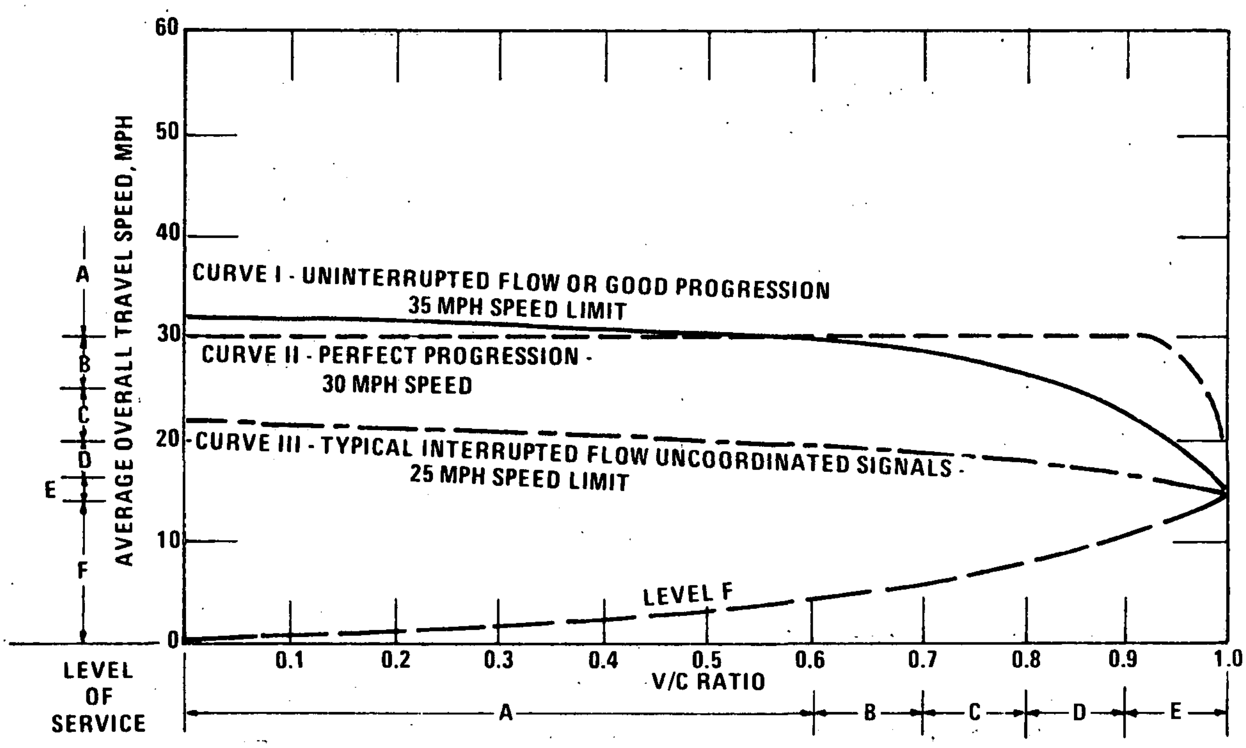

FIGURE 5-6 TYPICAL RELATIONSHIPS BETWEEN V/C RATIO AND AVERAGE OVERALL TRAVEL SPEED, IN ONE DIRECTION OF TRAVEL, ON URBAN AND SUB-URBAN ARTERIAL STREETS

SOURCE: REFERENCE [22].

Analysis of trip generation for the land use categories and vehicle classes, indicate that the probable fraction of HG and DL vehicles generated by residences and commercial land uses is so small as to be far less than the probable error of the trip generation rate for these land uses.

From the average distribution of trucks cited in reference [8], the following gross vehicle classification factors have been selected:

AG	automobile, gasoline	.804
LDT	light duty truck, gasoline	.118
HDG	heavy duty vehicle, gasoline	.046
HDD	heavy duty vehicle, diesel	.032
	TOTAL	1.00

These factors should produce a reasonable and conservative estimate of truck distribution. They are generally applicable, without correction, where the study area is predominantly residential, or where there is a relatively uniform distribution of land uses, or where the amount of development likely to generate about average numbers of HG and DL trips is not significantly large.

However, some study areas are likely to have large, if not dominant truck generating land uses such as manufacturing and wholesaling/warehousing. A method to adjust the gross factors in these study areas has been developed since these land uses have been found to generate above-average truck trips. The method is based on a ratio of the number of trips generated by manufacturing, wholesaling and warehousing to the sum of all trips in study area. The factor, F_T, describes the significance of above average truck-generating land uses. The logic of this approach is based on the premise that normal distribution of HHG and HDD trucks is about .07. If all the trips generated by large truck generators exceed .07 of all "other" study area trips, this is an indication of abnormal distribution. Therefore, the excess (over .07) would represent a reasonable correction amount to be distributed among GH and DL trucks, and subtracted from automobile. Light duty truck is assumed to remain constand. If F_T were less than .07, conditions would be considered "average" and no correction would be required.

The correction should be applied as follows:

Assume $F_T = 0.17$

then .17 - .07 = .10 which is the required amount of the correction.

The adjusted truck factors are:

AG = .804 - .10 = .704

LOT = .118

HDG = .046 + .8(.10) = .04 + .08 = <u>.126</u>

HDD = .032 + .2(.10) = .01 + .02 = <u>.052</u>

VI. MOTOR VEHICLE EMISSION FACTORS

Emissions of the five criteria pollutants resulting from motor vehicle operation can be calculated using the EPA publication, Compilation of Air Pollution Emission Factors, Second Edition [8]. This publication is commonly referred to as "AP-42" and is regularly updated as research of the emission characteristics of all sources continues. The latest update to this publication is Supplement 5, issued in December 1975. This supplement prescribes a number of changes to the methodology for computing motor vehicle emissions presented in earlier versions of AP-42. It is expected that further updates to mobile source emission factors will be included in Supplement 7 which should be issued in the beginning of 1977. The methodology presented in this workbook is based on Supplement 5 and is expected to be consistent with future updates; only the emission factors are expected to change.

The Clean Air Act originally required emissions of three motor vehicle-related pollutants to be reduced 90 percent from the 1971 model year emissions before 1977. Amendments to this Act have subsequently relaxed these standards and it is expected that further relaxations will be enacted during 1976. The result of the Act and its amendments is that vehicles of each model year after 1967 have a different new vehicle emission rate, react differently to changes in speed, ambient temperature, and operating temperature, and deteriorate with age at different rates.

To account for this variation, AP-42 presents a tabulation of the average emission rate for each model year for the calendar years 1971 through 1980, 1985, and 1990. Also included are equations which describe the variation in emissions with ambient temperature, operating temperature, and speed, for each model year. These tables represent emissions projections based on the present schedule for implementation of emission controls. Any changes in this timetable will be reflected in future Supplements to AP-42, however, close attention should be paid to changes in the Act as the delay time in issuing a supplement is relatively long. AP-42 presents a table of several emissions standards and the subsequent deterioration factors which can be substituted for the existing tables on an interim basis until issuance of a future supplement by EPA.

The basic equation used to calculate a composite emission factor for a given calendar year and pollutant* is based on the Federal Test Procedure (FTP) methodology.** The equation is:

$$e_{npstwx} = \sum_{i=n-12}^{n} (c_{ipn} m_{in} v_{ips} z_{ipt} r_{iptwx} + m_{in} (f_i + e_i))$$

where: e_{npstwx} = Composite emission factor in grams per mile for calendar year (n), pollutant (p), average speed (s), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

c_{ipn} = The FTP mean emission factor for the ith model year vehicles during calendar year (n) and for pollutant (p)

m_{in} = The fraction of annual travel by the ith model year vehicles during calendar year (n)

v_{ips} = The speed correction factor for the ith model year vehicles for pollutant (p), and average speed (s)

z_{ipt} = The temperature correction for the ith model year vehicles for pollutant (p) and ambient temperature (t)

r_{iptwx} = The hot/cold vehicle operation correction factor for the ith model year vehicles for pollutant (p), ambient temperature (t), percentage cold operation (w), and percentage hot start operation (x)

f_i = Crankcase hydrocarbon emission rate in grams per mile from vehicles of model year (i)

e_i = The evaporative hydrocarbon emission factors in grams per mile for each model year (i). This factor includes both diurnal losses and "hot soak" emissions.

This equation represents the methodology to compute emissions for all regions, vehicle types and calendar years using the Federal Test Procedure (FTP). AP-42 presents emissions for calendar years 1971 and 1972 using the

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*Carbon monoxide, nitrogen oxides, and hydrocarbons. Emissions of sulfur oxides and particulates are computed by employing relatively simple methodology discussed in Chapter VIII.

**This procedure is described in Section 3.1.2 of AP-42, Supplement 5 [8].

results of actual vehicle testing. Emissions from vehicles after 1972 have been estimated based on extrapolation of previous tests. These emission factors and correction factors are presented in Appendix D of AP-42, Supplement 5 [8]. This appendix provides a more general methodology for computing emissions and is used in development of the worksheets presented in Chapter VII.

A. DESCRIPTION OF EMISSION FACTOR COMPONENTS

This section describes each of the variables presented in Equation 6-1. A general description of each component for each vehicle class (automobile, light-duty truck (LDT), heavy-duty gasoline-powered vehicle (HDG), and heavy-duty diesel-powered vehicle (HDD)) is presented including reference to the specific tables in AP-42 [8]. The impact of several vehicle classes (motorcycles, construction equipment, etc.) have not been included in this analysis. Also the impact of transportation control strategies which affect individual vehicle emissions such as inspection/maintenance plans and retrofit devices are not addressed. The user is referred to AP-42 for further information if these subjects will have a significant impact.

1. Mean Emission Factor (C_{ipn})

This factor represents the emissions (including deterioration) of a given pollutant (p) from the ith model year during calendar year (n). This factor is presented for three regions (low altitude, high altitude, and California) and three pollutants in Tables D1.1 through D1.20 for automobiles. Emissions of the three pollutants for LDT and HDG are presented in Tables D2.1 through D2.10 and D4.1 through D4.10, respectively, for low altitude only. Section D4.5 presents a methodology for estimating high altitude and California emission factors for these vehicle classes. Emission factors for HDD are presented in Table D5.1 for three pollutants and all years. These factors are applicable for both low and high altitude operation. Section D5.4 presents the methodology to estimate HDD emissions in California.

2. Weighted Annual Travel (m_{in})

This variable reflects the relative miles traveled of the ith model year during calendar year (n). This variable is calculated for the 12 years prior to year (n) representing a total of 13 values. The value of m_{in} which represents the oldest model year (year (n-12)) also includes vehicles older than 12 years in order to include all vehicles in the weighting. The equation used to compute m_{in} is:

$$m_{in} = \frac{a_i b_i}{\sum_{j=n-12}^{n} a_j b_j}$$

where: a_i = Number of vehicles of model year (i) in calendar year (n)

b_i = Average number of miles driven by vehicles of model year (i) in calendar year (n)

If the data required to compute these values is not available, national averages for m_{in} which can usually be applied for any calendar year (n) are presented for automobiles, LDT, HDG, and HDD in Tables D1.22, D2.11, D4.11, and D5.2, respectively, of AP-42.

3. Speed Correction Factor (v_{ips})

This factor adjusts the emissions of pollutant (p) from a vehicle of model year (i) traveling at a speed (s). The mean emission factors (c_{ipn}) presented above are calculated for a single speed for each vehicle type (18 mph for HDD, 19.6 mph for all other classes). Vehicle speed, however, has a significant effect on emission rates. Equations for (v_{ips}) are presented for each region and year in Table D1.23 for automobiles and LDT (Table D2.12 is identical to Table D1.23). Table D4.12 presents speed factors for HDG and Equations D5.2 and D5.3 present an adjustment factor for HDD. For the vehicle classes other than HDD, the effective range of these equations is 15 to 45 miles per hour. At speeds lower than 15 mph, Tables D1.24, D2.13, and D4.13 should be applied to the respective classes. Guidance in estimating emissions at speeds greater than 45 mph is not provided in AP-42. An assumption which can be made is that the speed correction factor for 45 mph is applicable at all speeds greater than 45 mph.

4. Ambient Temperature Correction Factor (z_{ipt})

This correction factor adjusts the pollutant (p) emission rate (c_{ipn}) of vehicles of the ith model to account for ambient temperature (t°F). This factor is applied only if (t) is outside the FTP range of 68-86°F. Equations for z_{ipt} are presented in Table D1.25 for automobiles and light-duty trucks, providing separate equations for vehicles equipped with catalytic converters and those without. (Table D1.25 is identical to Table D2.14.) HDG and HDD emissions are assumed not to vary with ambient temperature (z_{ipt} = 1.0).

5. Operating Temperature Correction Factor (r_{iptwx})

This factor adjusts the pollutant (p) emission factor of vehicles of the ith model year as a function of ambient temperature (t), percent of vehicles operating from cold start (w), and percent of vehicles operating from hot start (x). This factor is applied only to automobiles and LDT; heavy-duty vehicles are assumed to be operated only in the warmed-up state (r_{iptwx} = 1.0). This variable is applied if the mix of light-duty vehicles among cold start, hot start, and warmed-up varies significantly from the FTP standard of 20 percent, 27 percent, and 53 percent, respectively. Equations D1-2 and D1-3 present equations to calculate (r) for pre-1975 and post-1974 model years, respectively. Equations for f(t) and g(t) are identical for automobiles and LDT and are presented in Table D1.25.

6. Crankcase Hydrocarbon Emission Factor (f_i)

This quantity is the amount of hydrocarbons emitted from the crankcase of model year (i) vehicles. This factor has no effect when computing carbon monoxide and nitrogen oxide emissions (f_i = 0.0). Tables

D1.26, D2.15, and D4.14 present crankcase emissions for automobiles, LDT, and HDG, respectively. Crankcase emissions from HDD are negligible. Crankcase hydrocarbon emissions have been eliminated in all post-1967 automobiles and trucks (f_i = 0.0).

7. Evaporative Hydrocarbon Emissions (e_i)

This quantity is an estimate of hydrocarbon losses from the carburetor and fuel systems from vehilces of the ith model year. This factor has no effect on the calculation of carbon monoxide and nitrogen oxide emissions (e_i = 0.0). This factor is calculated by:

$$e_i = (g_i + k_i d)/t$$

where: g_i = diurnal evaporative loss (grams/day)
k_i = hot soak evaporative emissions (grams/trip)
d = average number of trips per day
t = average number of miles traveled per day

Table D1.27 presents values of g_i and k_i for automobiles. Conversion to grams/mile was achieved using an assumption of 3.3 trips per day and a total of 29.4 miles traveled per day. Tables D2.15 and D4.14 present values of e_i for LDT and HDG, respectively. Evaporative losses from diesels are negligible.

VII. COMPUTATION WORKSHEETS AND INSTRUCTIONS

A detailed step-by-step procedure is presented in the following sections for the computation of land use development, traffic generation, and the resulting air pollutant emissions associated with a planned Major Project. A series of computation worksheets (summarized in Table 7-1) are the vehicle for this procedure.

A. LAND USE MODEL

Predictive equations have been developed for total land use development in an area of influence ten years after the initiation of a Major Project (see Section III). These equations have been incorporated into a set of worksheets, presented below, that can be used to project future land use development. These equations are applicable to areas where a large Residential, Industrial, or Office Major Project will be, or already has been, built. They do not constitute a general land use model. Specifically, a proposed Residential project's final size should be in the range of 1,100-5,300 total dwelling units, and the final size of an Industrial or Office project should be in the range of 3,600-9,100 employees. The use of the following worksheets should be limited to situations where the Major Project is in this size range.

Unless otherwise noted, the variables defined in Worksheets RLUM-1, RLUM-2, IOLUM-1, IOLUM-2, and IOLUM-3 correspond to the year of project initiation, which could be now, in the past, or the near future. They are listed under the geographical area they correspond to, e.g., Item 2 on Worksheet RLUM-1 is the number of dwelling units in the area of influence. The size of the area of influence (Item 1 on Worksheets RLUM-1 and IOLUM-1) in all cases is either 10,000 acres or 40,470,000 m^2, depending upon whether English or Metric units are used. The land use quantities predicted refer to the area of influence ten years after the initiation of the Major Project. It is assumed that the Major Project will be completed by the end of this ten year interval.

TABLE 7-1

SUMMARY OF COMPUTATION WORKSHEETS

RLUM-1 through RLUM-7	Calculation of Estimated Land Use Residential Model
IOLUM-1 through IOLUM-7	Calculation of Estimated Land Use Industrial-Office Model
LUM-1, LUM-2	Calculation of Land Use Model Confidence Intervals
LUM-3	Summary of Land Use Predictions
VMT-1	Calculation of Vehicle Trips
VMT-2	Calculation of Gross VMT
VMT-3	Calculation of VMT by Facility Type
VMT-4	Calculation of Vehicle Classification Proportions
VEM-1	Calculation of Motor Vehicle Emission Rate for a Specific Vehicle Category
VEM-2	Calculation of Composite Motor Vehicle Emission Factor
EMI-1	Calculation of Stationary Source Emissions
EMI-2	Calculation of Motor Vehicle Emissions
EMI-3	Summary of Emissions

Separate complete worksheets are provided for Residential (Section VII.A.1) or Industrial/Office (Section VII.A.2) projects. In both cases, the worksheets have been designed to allow the computation of land use in either English or Metric units. The convention used throughout is that items or numbers referring to Metric units are placed immediately following corresponding English unit items in parentheses. A second convention used in the worksheets is that some numbers are expressed in exponential notation due to their extremely small or large size. For example, 3.35E9 = 3.35×10^9 = 3,350,000,000 and 4.02E-5 = 4.02×10^{-5} = 0.0006402. Finally, after computing the projected total land uses, confidence intervals can be obtained for each projection using Worksheets LUM-1 and LUM-2, discussed in Section III. A.3.

1. Residential Land Use Model

The following step-by-step procedure should be followed:

a. Worksheets RLUM-1 and RLUM-2

Enter the values of the variables listed in Items 1 through 39 and perform the arithmetic operations indicated. All items must be completed.

b. Worksheets RLUM-3, RLUM-4, and RLUM-5

Enter the values of the variables called for in the far left hand column from the two previous worksheets. For each variable entered, perform the indicated multiplications between the variable and the constants that appear in the Land Use Category columns, and record the result in the blank space below each constant. For example, if the value of item 3 is 0.80 (English units), then the quantity 0.80 x 8910 = 7128 is recorded in the first blank space in Column L_1. Proceed and fill in all these worksheets.

Next, sum up the recorded quantities in each of the 12 Land Use Category columns and enter the result on Worksheet RLUM-5 on the now labeled "Σ Columns". Add in the appropriate constants given in the next row and enter the total predicted land uses in the final row. Revise any negative total land use quantities up to the value of 0.

c. Worksheet RLUM-6 and RLUM-7

Enter projected percentages for the disaggregation of Residential and Commercial land use in the Area of Influence at project completion in Items 40 through 47. These percentages should take account of the local factors which will most likely effect the density of future development in the Area of Influence. In the absence of such data, default values are provided which refer to an average Major Project and the development patterns of the period 1960-1970.

Perform the multiplications indicated in the second half of the worksheet and record the values of final projected land use in Items 48 through 65.

2. Industrial/Office Land Use Model

The following step-by-step procedure should be followed:

a. Worksheets IOLUM-1, IOLUM-2, and IOLUM-3

Enter the values of the variables listed in Items 1 through 44 and perform the arithmetic operations indicated. All items must be completed.

b. Worksheets IOLUM-4, IOLUM-5, and IOLUM-6

Enter the values of the variables called for in the far left hand column from the two previous worksheets. For each variable entered, perform the indicated multiplications between the variable and the constants that appear in the Land Use Category columns, and record the result in the blank space below each constant. For example, if the value of item 3 is 0.80 (English units), then the quantity 0.80 x 2480 = 1984 is recorded in the first blank space in column L_1. Proceed and fill in all three worksheets.

Next, sum up the recorded quantities in each of the 12 Land Use Category columns and enter the result on Worksheet IOLUM-5 on the now labeled "Σ Column". Add in the appropriate constants given in the next row and enter the total predicted land uses in the final row. Revise any negative total land use quantities up to the value of 0.

c. Worksheet IOLUM-7

Enter projected percentages for the disaggregation of Residential and Commercial land use in the Area of Influence at project completion in Items 45 through 52. These percentages should take account of the local factors which will most likely effect the density of future development in the Area of Influence. In the absence of such data, default values are provided which refer to an average Major Project and the development patterns of the period 1960-1970.

Perform the multiplications indicated in the second half of the worksheet and record the values of final projected land use in Items 53 through 70.

3. <u>Computing Confidence Intervals</u>

The preceding worksheets are an application of predictive equations that have been developed for land use in various categories. These equations are of the form:

$$Y = b_0 + \sum_{i=1}^{n} b_i X_i$$

where: Y is the land use being predicted

$X_1, X_2, \ldots X_n$ are the independent variables used in the prediction

$b_0, b_1, \ldots b_n$ are the model coefficients

The variables $X_1, \ldots X_n$ are those which are recorded in the far left column of Worksheets RLUM-3,4,5 and IOLUM-4,5,6. The model coefficients $b_0, b_1, \ldots b_n$ are the constants listed in the center of these worksheets.

For a given land use equation, confidence intervals can be specified in the form:

$$Y \pm tV(Y)^{1/2}$$

where t is the t-statistic for the regression of the model equation and V(Y) is the variance of Y. V(Y) can be expressed as:

$$V(Y) = \sum_{i=1}^{n} \sum_{j=1}^{n} X_i X_j \text{ Covariance } (b_i b_j)$$

All of the necessary data for computing confidence intervals are contained on the previous worksheets and in Appendix A to this report, which summarizes the statistical output for the predictive land use equations. To compute confidence intervals for each of the 18 categories of final projected land use listed on Worksheets RLUM-6 and IOLUM-6, fill out 18 sets of Worksheets LUM-1 and LUM-2.

a. Worksheet LUM-1

Enter the final projected land use category on the first line, find the corresponding dependent variable name and general land use category from Table 7-2 and place it on the second line. From the appropriate Land Use Worksheets (RLUM-3,4,5 or IOLUM-4,5,6), find which predictor variables are used under the column corresponding to the general land use category, find the prediction variable names from Table 7-3 (Residential) or 7-4 (Industrial-Office) and record these names along with the corresponding variable values from the far left column of the worksheets under items 1 through 6. For example, for the final projected land use category "Single Family Attached", the dependent variable name is "RES" and the general land use category is "L_1". Assuming the Residential model from Worksheets RLUM-3,4,5 and Table 7-3, the predictor variable names are found to be "DUACRE, DELP2, DISCBD, HWYINT, MPR70, and SEWER". The corresponding values would be entered for items 3, 20, 4, 5, 33, and 30, respectively.

TABLE 7-2

LIST OF DEPENDENT VARIABLE NAMES FOR EACH FINAL PROJECTED LAND USE CATEGORY

Final Land Use Category	Dependent Variable Name	General Land Use Category
Single Family Attached	RES	L_1
Single Family Detached	RES	L_1
Mobile Homes	RES	L_1
Multifamily Low Rise	RES	L_1
Multifamily High Rise	RES	L_1
Commercial <50K	COMM	L_2
Commercial 50-100K	COMM	L_2
Commercial >100K	COMM	L_2
Office	OFFICE	L_3
Manufacturing	MANF	L_4
Non-Expressway Highway Lane Distances	HWLMNX	L_5
Wholesale-Warehousing	WHOLE	L_6
Hotels, Motels	HOTEL	L_7
Hospitals	HOSPTL	L_8
Cultural Facilities	CULTUR	L_9
Churches	CHURCH	L_{10}
Educational Facilities	EDUC	L_{11}
Recreational Facilities	REC	L_{12}

TABLE 7-3

LIST OF PREDICTOR VARIABLE NAMES
FOR THE RESIDENTIAL MODEL

Predictor Variable Item Number (Worksheets RLUM-3,4,5)	Predictor Variable Name
3	DUACRE
20	DELP2
4	DISCBD
5	HWYINT
7	OFFACR
21	EMP60
9	VACACR
23	DELEMP
11	MANACR
26	AUTO2
16	MINC
32	MPR68
33	MPR70
28	OFFVAC
14	ZRES
27	AUTO
35	INCMPL
36	UNIV
30	SEWER
38	MPKIDS
39	MPACRE

TABLE 7-4

LIST OF PREDICTOR VARIABLE NAMES
FOR THE INDUSTRIAL/OFFICE MODEL

Predictor Variable Item Number (Worksheets IOLUM-3,4,5)	Predictor Variable Name
3	DUACRE
5	VACACR
36	OFFVAC
7	VACHSG
8	DISCBD
12	ZCOMM
16	OFFACR
42	MPE70
17	RRMI
13	ZOFF
29	MINC
19	MANACR
32	DELEMP
27	MINCC
20	HWYINT
22	WWEA
14	ZIND
40	SEWER
24	NONHSE
39	ENERGY
30	EMP60
43	MPACRE
44	PVTSCH
41	MPET2
35	AUTO

Locate the statistical output in Appendix A corresponding to the appropriate Major Project type (Residential or Industrial/Office) and dependent variable name. For each pair of predictor variables listed on this Worksheet and LUM-2, find and record the covariance from the "variance-covariance matrix" in Appendix A. Continuing the previous example, we would record "0.677537E7" under the covariance for the pair 1 and 1 (DUACRE and DUACRE), "-353084" for the pair 1 and 2 (DUACRE and DELP2), etc.

Compute items 7 through 42 by performing the indicated multiplications. Note that equations with less than 6 predictor variables will have less covariances to record and multiplications to perform.

b. Worksheet LUM-2

Compute the variance of the dependent variable by summing up Items 7 through 42. Record the t-statistic of the predictive equation from Appendix A, and perform the equations noted in items 44 through 48 to obtain the confidence interval. Note that final projected land use categories that are disaggregations of total Residential or total commercial land use will require calculation of Items 1 through 46 only once in the general land use category.

c. Worksheet LUM-3

Enter the projected final size of the Major Project in Items 49 through 56. Copy the final projected land uses/excluding Major Project from Items 48 through 65 of Worksheet RLUM-6 or from Items 53 through 70 of Worksheet IOLUM-6, depending upon the Major Project type, and perform the indicated additions to obtain total projected land use (including Major Project).

B. CALCULATION OF VEHICULAR TRAFFIC

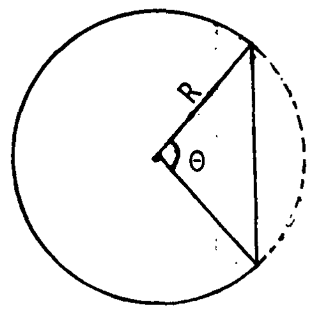
This section contains procedures and guidelines that are designed to facilitate the computation of VMT. A step by step procedure is provided. The virtue of this model is its relative simplicity. Nevertheless, the application of the model requires sound judgment in either modifying or accepting the default trip rates and trip lengths as representative of a particular study area. Familiarity with these concepts and their typical values is desirable.

1. Worksheet No. 1 (VMT-1)

- Compute the effective radius of the area of influence and enter on line no. 1. In most instances the area will be a circle, so 2.23 miles (3589 meters), should be entered.
- However, in some areas a circle with a 2.23 mile radius will include a coastline or an impenetrable geographical barrier. In order to maintain the same area (i.e., 10,000 acres (4.05×10^7 square meters) the radius must be adjusted, i.e.,

$$R, \text{miles} = \frac{15.625}{\pi - \frac{1}{2}(\theta - \sin\theta)}$$

$$R, \text{meters} = \frac{40466351}{\pi - \frac{1}{2}(\theta - \sin\theta)}$$



N.B. θ is in radians

Enter the total amount of land use for each category in column 2. The first five categories (i.e., residential) are in units of dwelling units. The next ten categories are in units of 10^3 square feet (or square meters) and the last category, recreation, should be entered in acres. The definition of each category is shown in Table 2-1.

Enter the work trip rate, T_1, in column 3 and the other (i.e., non-work) trip rate, T_2, in column 5. Default trip rates are shown in Table 5-2.

Compute the work trips and other trips by taking the product of, respectively, columns 2 and 3 and columns 2 and 5. Enter the results in columns 4 and 6.

Compute the total work trips and total other trips by summing respectively, column 4 and 6. Enter the results on lines 23 and 24.

2. <u>Worksheet No. 2 (VMT-2)</u>

- Copy the values from lines 23 and 24 on VMT-1 to the lines with the circled numbers.
- Determine the work trip length and the other trip length in miles (or meters) according to the instructions on page . Enter the results in column 25 as well as L_r from line 1.
- Compute the total uncorrected VMT by multiplying the total work trips and total other trips by the work trip length and the other trip length.
- Compute the total residential work trips and total residential other trips by adding the first six entries in columns 4 and 6 on worksheet no. 1. Enter the sums on worksheet no. 2 on, respectively, lines 30 and 34.
- Determine a value for the proportion of work and other trip lengths less than L_r, through the use of either local information or the default value 0.40.
- Compute the VMT correction by multiplying the duplicated trips by the radius of the area of influence. After subtraction, enter the net VMT on lines 38 through 41.
- Enter the proportion of VMT occurring in the peak hour on line 42.
- The difference between 1 and this proportion are the VMT occurring during the off peak hour. Enter this number on line 43.
- From local information or through the uses of Figures 5-3 and 5-4, determine the proportion of distance traveled on each facility type (i.e., local streets, arterials, and expressways) for the average work trip and other trip. Enter these values on lines 44 through 49.

3. <u>Worksheet No. 3 (VMT-3)</u>

- As indicated, the VMT on each facility type, for the peak and off peak time interval, for both the impact area and area of influence.

4. Worksheet No. 4 (VMT-4)

- Compute the number of trips that are manufacturing or warehouse related by adding lines 19, 20, 21, and 22 on VMT-1; enter the sum on line 62.
- Compute the proportion of trips that are warehousing related.
- If the proportion, line 63, is greater than 0.05, determine the adjustment factor (i.e., the excess above 0.05) and calculate the vehicle classification factors.
- Determine the average route speeds from local information or through the use of Figures 5-19and 5-20. Otherwise use the default values indicated below:

69.	50 mph	72.	37 mph
70.	28 mph	73.	20 mph
71.	18 mph	74.	15 mph

C. CALCULATION OF MOTOR VEHICLE EMISSIONS

This section contains guidelines and worksheets that can be employed to calculate motor vehicular emissions. The methodology for computing vehicular emissions is derived from the EPA publication Compilation of Air Pollutant Emission Factors, Second Edition [8]. This publication is generally known as "AP-42" and has been updated by means of five supplements at this writing. Chapter VI presents further information on expected updates to these emission factors. The methodology to compute vehicle emissions which is presented in this section relies heavily on Appendix D of AP-42. It is essential that this document (including all updates) be available before beginning these calculations.

The motor vehicular traffic data required to estimate emissions are calculated in the previous section. For either the 10,000 acres of influence or the larger impact area, the following is required:

- Vehicle miles traveled (VMT) on each facility type for the peak hour and off peak.
- Average route speed of the VMT on each facility type for the peak hour and the off peak.
- Vehicle class distribution. This is assumed to be constant between facility types and peak/off peak time intervals.

In addition, as discussed in Chapter VI, several decisions must be made regarding the applicability of the default assumptions in the emission equation (i.e., the use of a national vehicle age distribution, and the assumption of the relative number of cold starts).

1. Motor Vehicle Emissions Worksheet No. 1 (VEM-1)

This worksheet should be completed for each vehicle type, pollutant (CO, HC, NO_x), and speed (i.e., facility type and peak-off peak time interval) of interest. In the case of the GEMLUP traffic sub-model, this would require 72 (four vehicle types, three pollutants, and six average route speeds) different sheets. It is essential that givens, i.e., vehicle type, speed, design, year, etc, lines 1 through 8 be specified before beginning the computation. It is often helpful to note the model year (column 9) which corresponds to each vehicle age so that model year dependent factors are computed correctly.

The AP-42 (Appendix D) tables which will be referred to in this discussion have been described in detail in Chapter VI. For this reason, the specific table or tables to be used in computing each factor will not be included in this discussion. The reader is referred to Chapter VI for both a further description of each of the components and on enumeration of the tables to be used to compute each component. With this information, the following procedures can be used to compute emissions.

- Fill in the model year corresponding to each vehicle age. The design year (line 4) is Age=1, Age=2 is the design year minus 1, etc. Finally, Age $\geq$ 13 is the model year twelve years prior to the design year.
- Locate the table in AP-42 corresponding to the correct vehicle type (line 1), pollutant (line 2), design year (line 4), and region (line 5). Fill in column 11 with the emission rate (C_{ipn}) which corresponds to each model year.
- Fill in column 12 with the vehicle age weighting factors (M_{in}) corresponding to the correct vehicle type (line 1) and vehicle age (column 10).
- Calculate the speed correction factor (column 13) for the correct vehicle type (line 1) and each model year (column 9) using the design speed (line 3). See Chapter VI for the correct application of this factor.
- Fill in the ambient temperature correction factor (column 15) for model year using the ambient temperature (line 8). This factor is identical for automobiles and light-duty trucks and is negligible for heavy-duty vehicles (Z_{ipt}=1.0).
- Insert in column 15 for each model year, the appropriate operating temperature correction factor (r_{iptws}) based on the percent cold starts (line 6) and hot starts (line 7). Again, this factor is not applicable to heavy-duty vehicles.
- Calculate the emission contribution (column 16) of each model year by multiplying columns 11 through 15 and writing the results in column 16.

- If the pollutant for which the emission rate being calculated is not hydrocarbons, then add the emission contribution (column 16) of each model year. The sum is inserted on line 22, the final average emission factor (e_n).
- For hydrocarbons, non-exhaust emissions must be considered. In column 17, fill in the crankcase emission factor appropriate for the vehicle type and model year.
- In column 18, fill in the evaporative emission factor in grams per mile for the vehicle type and model year.
- Complete column 19 identically to column 12.
- Add columns 17 and 18 and multiply the sum by column 19 for each model year. Insert the result in column 20.
- Add columns 16 and 20 for each model year and place in column 21. This is the model year weighted hydrocarbon emission factor (e_{T_i}).
- The summation of column 21 should be inserted on line 22. This is the final hydrocarbon emission factor (e_n).
- This procedure must be carried out for each vehicle class.

2. <u>Worksheet No. 2 (VEM-2)</u>

Worksheet No. 2 is employed to calculate the composite emission rate (i.e., the weighted average of the emission rates of the four vehicle classes, AG, LDT, HDG, HDD. The weighting factors, the proportion of VMT in each vehicle class, are obtained from the VMT-4 worksheet. The emission rates for each vehicle class are calculated on the VEM-1 worksheet in the case of carbon monoxide, hydrocarbons, and oxides of nitorgen.

Emissions of particulates and sulfur oxides are relatively invariant with mode of operation. Only the change to using unleaded gasoline in catalytic-equipped vehicles has resulted in a different particulate emission rate. Table D.1-21, D.2-16, D.4-15, and D.5-4 of AP-42 present emission factors of particulates and sulfur oxides for automobiles, LDT, HDG, and HDD, respectively. The following equation is used to calculate the particulate emission factor for each vehicle class.

$$e_{pn} = 0.01\ (e_{nc}e_{nc}) + (100 - P_{nc}e_{ns})$$

where,

e_{pn} = particulate emission factor in year (n) including exhaust, tire, and brake wear emissions

P_{nc} = percent vehicles equipped with catalytic converters in year (n)

e_{nc} = total particulate emission rate for vehicles equipped with catalytic converters

e_{ns} = total particulate emission rate for vehicles not equipped with catalytic converters.

The sulfur oxide emission factor can be established directly from AP-42.

- Insert the correct emission rate for the pollutant (line 2) in column 23. In the case of carbon monoxide, hydrocarbons, and oxides of nitrogen, this value is line 22 on worksheet VEM-1 for each vehicle class. In the case of particulate matter, the above equation is employed. The sulfur oxide emission rate is obtained from AP-42.
- Insert in column 24 the proportion of VMT by each vehicle class from worksheet VMT-4, lines 65 through 68.
- Compute the product of columns 23 and 24 and enter in column 25.
- Sum the values in column 25 and insert the answer on line 26. This is the composite emission factor for the speed in line 3.

A comprehensive example of the calculations for computing emissions of carbon monixide, hydrocarbons, and nitrogen oxides is presented in Chapter IX.

D. CALCULATION OF EMISSIONS

1. Worksheet No. 1 (EMI-1)

This worksheet is employed to calculate stationary source emissions in the area of influence. It should be filled out for each fuel type (i.e., gas, oil) and pollutant, as well as electricity consumption.

- Enter the amount of land use in units of dwelling units, 10^3 square feet (or square meters) of floor area, or acres (or square meters) in Column 1. These values are obtained from worksheet LUM-3, the product of lines on the worksheet and the proportion of land use in that category using a particular fuel type. The proportion of a land use category using a particular fuel type should be obtained from local utulity companies or from national information [23, 24,].
- Enter the process emission factor in column 2, the space-heating emission factor in column 4, the space cooling emission factor in column 6. These values can be found by employing the tables in Chapter II. The process emission factor must be adjusted if a time period other than one year is under consideration. The space heating and space cooling emission factors must first be multiplied by the number of degree days or operating hours.
- Total manufacturing land use should be entered on line 17.

  The composite industrial emission factor, obtained from Chapter II or from Volume II of this report is entered on line 18.
- Total emissions are calculated and entered on lines 8, 9, 10, and 19.

2. Worksheet No. 2 (EMI-2)

This worksheet is used to calculate motor vehicle emissions in the area of influence and in the impact area. It is filled out five times, once for each pollutant.

- Enter in columns 12 and 13 the speed and amount of VMT in each category from worksheets VMT-3 and VMT-4.
- Enter in column 14 the emission factor from worksheet VEM-2 for the appropriate speed category.

- Compute emissions in each category by taking the product of columns 13 and 14. Sum the first six lines (line 16) and the second six lines (line 17).

3. Worksheet No. 3 (EMI-3)

This worksheet summarizes the emissions.

- On the first four lines enter the emissions for each pollutant in columns 21 through 25. These values are obtained from the EMI-1 worksheets, lines 8, 9, 10, and 19.
- The total stationary source emissions in the area of influence are summed in line 27.
- Enter the mobile source emissions from lines 15 and 16, worksheet EMI-2.
- Take the product of line 26, total electricity consumption, and the electric utility emission factors in Chapter II. Enter these products in line 29.
- Total emissions in the area of influence are computed by adding lines 27 and 15.
- Total emissions are computed by adding lines 27, 29 and 16.

EXHIBIT 7-1

WORKSHEET RLUM-1

RESIDENTIAL LAND USE MODEL VARIABLE DEFINITIONS

(For year t+0 unless otherwise noted)

AREA OF INFLUENCE

Size of Area of Influence in acres (or m^2)	1.__________
Number of dwelling units, excluding major project	2.__________
Dwelling units per acre (or m^2) = ② ÷ ①	3.__________
Distance from center of major project to nearest Central Business District in miles (or km)	4.__________
Projected number of limited-access highway interchanges in 5 years	5.__________
Number of office employees =	6.__________
Office employment per acre (or m^2) = ⑥ ÷ ①	7.__________
Projected percent developable land area in 10 years, excluding major project, in acres (or m^2)	9.__________
Number of manufacturing employees	10.__________
Manufacturing employment per acre (or m^2) = ⑨ ÷ ①	11.__________
Median income level of families and individuals	12.__________
Projected number of acres (or m^2) zoned for residential use in 5 years	13.__________
Projected percent residential zoned area = ⑬ ÷ ①	14.__________

COUNTY

Median income level of families and individuals	15.__________
Median income index - area of influence relative to county = ⑫ ÷ ⑮	16.__________
Total population	17.__________
Projected total population in 10 years	18.__________
Area of county in acres (or m^2)	19.__________
Projected population growth per acre (or m^2) = (⑱ - ⑰) ÷ ⑲	20.__________

EXHIBIT 7-2

WORKSHEET RLUM-2

RESIDENTIAL LAND USE MODEL VARIABLE DEFINITIONS

(For base year, t+0, unless otherwise noted)

Total employment	21.________________
Projected total employment in 10 years	22.________________
Projected employment growth per acre (or m^2) = (㉒ - ㉑) ÷ ⑲	23.________________
Total licensed automobile drivers	24.________________
Number of dwelling units	25.________________
Auto drivers per dwelling unit = ㉔ ÷ ㉕	26.________________
Auto drivers per acre (or m^2) = ㉔ ÷ ⑲	27.________________

METROPOLITAN AREA

Percent vacant office buildings	28.________________
Projected median income level in 2 years	29.________________

NEAREST MUNICIPALITY

Projected percent of land which will have public sewerage available in 5 years	30.________________

MAJOR PROJECT

Projected total dwelling units in 2 years	31.________________
Projected total dwelling units 2 years before project completion	32.________________
Projected total dwelling units at completion (ten years from now)	33.________________
Projected median income level in 2 years	34.________________
Set equal to 1 if ㉞ ÷ ㉙ < 0.85, otherwise = 0	35.________________
Set equal to 1 if a university exists within 3.23 miles (or 5.20 km) of the center of the major project, otherwise = 0	36.________________
Projected number of school age children in 2 years	37.________________
School age children per dwelling unit = ㊲ ÷ ㉛	38.________________
Area of major project in acres (or m^2)	39.________________

EXHIBIT 7-3

WORKSHEET RLUM-3

Land Use Categories

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
3 ______ x	8910 (3.35E9)	656 (2.47E8)	-400 (-1.50E8)			-269 (-1.01E8)						
20 ______ x	6790 (2.55E8)				40.5 (264000)							
4 ______ x	-351 (-20300)	-73.7 (-4260)	-14.1 (-814)		-2.79 (-2.79)	-11.4 (-658)				-4.42 (-255)	-25.5 (-1470)	
5 ______ x	-1360 (-126000)	-200 (-18600)	85.8 (7900)			97.1 (9020)						
7 ______ x		791 (2.97E8)	845 (3.18E8)					191 (7.18E7)				
21 ______ x		0.0032F (0.304)										
9 ______ x		0.0647 (0.00149)							0.00175 (4.02E-5)		0.0408 (9.37E-4)	
23 ______ x			601 (2.26E8)									
11 ______ x				1050 (3.95E8)								
26 ______ x					-135 (-217)							

(Metric coefficients are in parenthesis)

EXHIBIT 7-4

WORKSHEET RLUM-4

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
					Land Use Categories							
16 ______ x					46.6 (75.0)					202 (18800)		
32 ______ x					0.00595 (0.00957)							
33 ______ x	-0.682 (-63.4)					-0.0736 (-6.84)		0.0196 (1.82)				
28 ______ x						15.0 (1390)						
14 ______ x							-0.968 (-89.9)					
27 ______ x							230 (8.65E7)					
35 ______ x							-150 (-13900)					
36 ______ x									60.2 (5590)			
30 ______ x	41.2 (3830)										2.46 (229)	

(Metric coefficients are in parenthesis)

EXHIBIT 7-5

WORKSHEET RLUM-5

Variables	Land Use Categories L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
38 ____________ x											184 (17100)	
39 ____________ x												0.103 (417)
Σ Columns												
+ Constant	7200 (669000)	1380 (128000)	355 (33000)	761 (70700)	78.8 (127)	488 (45300)	81.7 (7590)	-23.9 (-2200)	2.54 (236)	-14.7 (-1370)	244 (22700)	-33.5 (-136000)
TOTAL LAND USE												

(Metric coefficients are in parenthesis)

EXHIBIT 7-6

WORKSHEET RLUM-6

RESIDENTIAL LAND USE MODEL

PROJECTED DISAGGREGATION OF LAND USE IN AREA OF INFLUENCE AT PROJECT COMPLETION

Residential Proportions		Default Values
Single family detached homes	40. ________	.61
Single family attached homes	41. ________	.03
Mobile homes	42. ________	.06
Multifamily low rise structures	43. ________	.29
Multifamily high rise structures	44. ________	.01

(Note (40) + (41) + (42) + (43) + (44) must = 1)

Commercial		
<50,000 ft^2	45. ________	.51
50-100,000 ft^2	46. ________	.20
>100,000 ft^2	47. ________	.29

(Note (45) + (46) + (47) must = 1)

FINAL PROJECTED LAND USE

In Dwelling Units

Single Family Attached	= (L_1) x (40)	48. ________
Single Family Detached	= (L_1) x (41)	49. ________
Mobile Homes	= (L_1) x (42)	50. ________
Multifamily Low Rise	= (L_1) x (43)	51. ________
Multifamily High Rise	= (L_1) x (44)	52. ________

In 1,000 ft^2 (m^2)

Commercial < 50K	= (L_2) x (45)	53. ________
Commercial 50-100K	= (L_2) x (46)	54. ________
Commercial > 100K	= (L_2) x (47)	55. ________
Office	= (L_3)	56. ________

EXHIBIT 7-7

WORKSHEET RLUM-7

RESIDENTIAL LAND USE MODEL

Manufacturing	= L_4	57. ______
Wholesale-Warehousing	= L_6	58. ______
Hotels, Motels	= L_7	59. ______
Hospitals	= L_8	60. ______
Cultural Facilities	= L_9	61. ______
Churches	= L_{10}	62. ______
Educational Facilities	= L_{11}	63. ______
Recreational Facilities	= L_{12}	64. ______

In miles (km)

Non-expressway highway lane distances	= L_5	65. ______

EXHIBIT 7-8

WORKSHEET IOLUM-1

INDUSTRIAL/OFFICE LAND USE MODEL VARIABLE DEFINITIONS

AREA OF INFLUENCE

Size of Area of Influence in acres (or m^2)	1.________
Number of dwelling units	2.________
Dwelling units per acre (or m^2) = (2) ÷ (1)	3.________
Number of developable acres (or m^2)	4.________
Percent developable area = (4) ÷ (1)	5.________
Vacant dwelling units	6.________
Percent vacant housing = (6) ÷ (2)	7.________
Distance from center of Major Project to nearest Central Business District in miles (or km)	8.________
Projected number of acres (or m^2) zoned for commercial use in 5 years	9.________
Projected number of acres (or m^2) zoned for office use in 5 years	10.________
Projected number of acres (or m^2) zoned for industrial use in 5 years	11.________
Projected percent commercial zoned area = (9) ÷ (1)	12.________
Projected percent office zoned area = (10) ÷ (1)	13.________
Projected percent industrial zoned area = (11) ÷ (1)	14.________
Number of office employees	15.________
Office employment per acre (or m^2) = (15) ÷ (1)	16.________
Railroad mileage (or km)	17.________
Number of manufacturing employees	18.________
Manufacturing employment per acre (or m^2) = (18) ÷ (1)	19.________
Projected number of limited access highway interchanges in 5 years	20.________
Number of wholesale and warehouse employees	21.________
Wholesale-warehouse employment per acre (or m^2) = (21) ÷ (1)	22.________
Nonhousehold population	23.________
Nonhousehold population per acre (or m^2) = (23) ÷ (1)	24.________

EXHIBIT 7- 9

WORKSHEET IOLUM-2

INDUSTRIAL/OFFICE LAND USE MODEL
VARIABLE DEFINITIONS

Median income level of families and individuals	25.	______
Current U.S. average income level for families and individuals	26.	______
Median income index-relative to U.S. average = (25) ÷ (26)	27.	______

COUNTY

Median income level of families and individuals	28.	______
Median income index-area of influence relative to county = (25) ÷ (28)	29.	______
Total employment	30.	______
Projected total employment in 10 years	31.	______
Projected employment growth rate = ((30) - (30)) ÷ (30)	32.	______
Total licensed automobile drivers	33.	______
Area of county in acres (or m^2)	34.	______
Auto drivers per acre (or m^2) = (33) ÷ (34)	35.	______

METROPOLITAN AREA

Percent vacant office buildings	36.	______
Cost of 1500 kWh of electricity (commercial rate)	37.	______
Average U.S. cost of 1500 kWh of electricity (commercial rate)	38.	______
Energy cost factor = (37) ÷ (38)	39.	______

NEAREST MUNICIPALITY

Projected percent of land which will have public sewerage available in 5 years	40.	______

EXHIBIT 7-10

WORKSHEET IOLUM-3

INDUSTRIAL/OFFICE LAND USE MODEL VARIABLE DEFINITIONS

MAJOR PROJECT

Projected total employees 2 years after project initiation	41.____________
Projected total employees at project completion	42.____________
Land area of completed major project in acres (or m^2)	43.____________
Set equal to I if a private school exists within 3.23 miles (or 5.20 km) of the center of the major project	44.____________
Size of floor area of completed major project in 1,000 ft^2 (or m^2) = 43.56 x (43) (English units) = (43) (Metric units)	45.____________

EXHIBIT 7-11

WORKSHEET IOLUM-3

Land Use Categories

Variables		L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
3 ______	x	2480 (9.32E8)	869 (3.27E8)			19.6 (128000)	726 (2.73E8)						
5 ______	x	2.05 (0.0471)			0.252 (0.00579)	0.00385 (1.53E-6)					0.0314 (721E-4)	0.0974 (0.00224)	
36 ______	x	563 (52300)				1.70 (2.74)							17.6 (71200)
7 ______	x	-128000 (-1.19E7)											
8 ______	x	-406 (-23400)						-11.5 (-664)					14.8 (37200)
12 ______	x		119 (11100)										
16 ______	x		-2090 (-7.86E8)					-249 (9.36E7)	-283 (1.06E8)				
42 ______	x		0.0553 (5.14)	-0.0273 (-2.54)									
17 ______	x			11.5 (664)							8.65 (499)	34.8 (2010)	
13 ______	x			68.9 (6400)									

(Metric coefficients are in parenthesis)

EXHIBIT 7- 12

WORKSHEET IOLUM-4

Land Use Categories

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
29 ________ x			507 (47100)									
19 ________ x			254 (9.55E7)					443 (1.67E8)				1.88 (3.08E9)
32 ________ x				10100 (3.80E9)			1180 (4.44E8)					1440 (2.36E10)
27 ________ x				-2620 (-253E5)								387 (1.57E6)
20 ________ x					-6.08 (-9.78)							
22 ________ x						7470 (2.81E9)						
14 ________ x						90.8 (8440)						
40 ________ x						11.4 (1060)				-1.07 (-99.4)		
24 ________ x								478 (1.8E8)				
39 ________ x									-34.6 (-3210)			

(Metric coefficients are in parenthesis)

EXHIBIT 7-13

WORKSHEET IOLUM-5

Land Use Categories

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
30 ______ x									0.00004 (0.00372)			
43 ______ x									0.0411 (9.44E-4)			
44 ______ x									12.6 (1170)			
41 ______ x										-0.0146 (-1.36)	0.0802 (7.45)	
35 ______ x												-615 (1.01E10)
Σ Columns												
+ Constant	-9530 (-885000)	-838 (77900)	-326 (-30300)	1120 (104000)	-25.7 (-41.4)	-1650 (-153000)	145 (13500)	-20.5 (-1900)	23.6 (2190)	-148 (-13700)	-925 (-85900)	-604 (-2.44E6)
TOTAL LAND USE												

(Metric coefficients are in parenthesis)

EXHIBIT 7-14

WORKSHEET IOLUM-7
INDUSTRIAL/OFFICE LAND USE MODEL

PROJECTED DISAGGREGATION OF LAND USE IN AREA OF INFLUENCE AT PROJECT COMPLETION

Residential		Default Values
Single family detached homes	45. ______	.68
Single family attached homes	46. ______	.02
Mobile homes	47. ______	.06
Multifamily low rise structures	48. ______	.23
Multifamily high rise structures	49. ______	.01

(Note (45) + (46) + (47) + (48) + (49) must = 1)

Commercial		
<50,000 ft^2	50. ______	.66
50-100,000 ft^2	51. ______	.14
>100,000 ft^2	52. ______	.20

(Note (50) + (51) + (52) must = 1)

FINAL PROJECTED LAND USE

In Dwelling Units

Single Family Attached	= (L_1) x (45)	58. ______
Single Family Detached	= (L_1) x (46)	54. ______
Mobile Homes	= (L_1) x (47)	55. ______
Multifamily Low Rise	= (L_1) x (48)	56. ______
Multifamily High Rise	= (L_1) x (49)	57. ______

In 1,000 ft^2 (m^2)

Commercial <50K	= (L_2) x (50)	58. ______
Commercial 50-100K =	= (L_2) x (51)	59. ______
Commercial >100K	= (L_2) x (52)	60. ______
Office	= (L_3)	61. ______
Manufacturing	= (L_4)	62. ______
Wholesale-Warehousing	= (L_6)	63. ______
Hotels, Motels	= (L_7)	64. ______
Hospitals	= (L_8)	65. ______
Cultural Facilities	= (L_9)	66. ______
Churches	= (L_{10})	67. ______
Educational Facilities	= (L_{11})	68. ______
Recreational Facilities	= (L_{12})	69. ______

In miles (km)

Non-expressway highway lane distances	= (L_5)	70. ______

EXHIBIT 7-15

WORKSHEET LUM-1

CONFIDENCE INTERVALS FOR PREDICTED LAND USE

Final Projected Land Use Category ______________________________

corresponds to Dependent Variable Name ____________ and General Category ____________

PREDICTOR VARIABLE

Name

Name	
____________	1. ____________
____________	2. ____________
____________	3. ____________
____________	4. ____________
____________	5. ____________
____________	6. ____________

COMPUTING VARIANCE OF DEPENDENT VARIABLE

(1) x (1) x Covariance ____________ = 7. ____________
(1) x (2) x Covariance ____________ = 8. ____________
(1) x (3) x Covariance ____________ = 9. ____________
(1) x (4) x Covariance ____________ = 10. ____________
(1) x (5) x Covariance ____________ = 11. ____________
(1) x (6) x Covariance ____________ = 12. ____________
(2) x (1) x Covariance ____________ = 13. ____________
(2) x (2) x Covariance ____________ = 14. ____________
(2) x (3) x Covariance ____________ = 15. ____________
(2) x (4) x Covariance ____________ = 16. ____________
(2) x (5) x Covariance ____________ = 17. ____________
(2) x (6) x Covariance ____________ = 18. ____________
(3) x (1) x Covariance ____________ = 19. ____________
(3) x (2) x Covariance ____________ = 20. ____________
(3) x (3) x Covariance ____________ = 21. ____________
(3) x (4) x Covariance ____________ = 22. ____________
(3) x (5) x Covariance ____________ = 23. ____________
(3) x (6) x Covariance ____________ = 24. ____________
(4) x (1) x Covariance ____________ = 25. ____________
(4) x (2) x Covariance ____________ = 26. ____________
(4) x (3) x Covariance ____________ = 27. ____________
(4) x (4) x Covariance ____________ = 28. ____________
(4) x (5) x Covariance ____________ = 29. ____________
(4) x (6) x Covariance ____________ = 30. ____________

EXHIBIT 7- 16

WORKSHEET LUM-2

CONFIDENCE INTERVALS FOR PREDICTED LAND USE

COMPUTING VARIANCE OF DEPENDENT VARIABLE

(5) x (1) x Covariance ____________	=	31. ____________
(5) x (2) x Covariance ____________	=	32. ____________
(5) x (3) x Covariance ____________	=	33. ____________
(5) x (4) x Covariance ____________	=	34. ____________
(5) x (5) x Covariance ____________	=	35. ____________
(5) x (6) x Covariance ____________	=	36. ____________
(6) x (1) x Covariance ____________	=	37. ____________
(6) x (2) x Covariance ____________	=	38. ____________
(6) x (3) x Covariance ____________	=	39. ____________
(6) x (4) x Covariance ____________	=	40. ____________
(6) x (5) x Covariance ____________	=	41. ____________
(6) x (6) x Covariance ____________	=	42. ____________

Sum (7) through (42) = 43. ____________

Standard Deviation of Dependent Variable = $\sqrt{(43)}$ 44. ____________

F - statistic of predictive equation 45. ____________

t - statistic of predictive equation = $\sqrt{(45)}$ 46. ____________

If Final Projected Land Use is Residential or Commercial, set equal to the disaggregation percentage 47. 100

± Confidence Interval = (46) x (44) x (47) ÷ 100 48. ____________

EXHIBIT 7-17

WORKSHEET LUM-3

FINAL LAND USE MODEL CALCULATIONS

MAJOR PROJECT

If Residential, total projected dwelling units at project completion, by the following types:

Single Family Detached	49.________
Single Family Attached	50.________
Mobile Homes	51.________
Multifamily Low Rise	52.________
Multifamily High Rise	53.________

If Industrial/Office, total projected land area in 1,000 ft^2 (or m^2), by the following types:

Office	54.________
Manufacturing	55.________
Wholesale-warehousing	56.________

TOTAL PROJECTED LAND USE (Including Major Project)

In Dwelling Units		RLUM-6*	or	IOLUM-6*	From Above	
Single Family Detached	=	(48)	or	(53)	+ (49)	57.________
Single Family Attached	=	(49)	or	(54)	+ (50)	58.________
Mobile Homes	=	(50)	or	(55)	+ (51)	59.________
Multifamily Low Rise	=	(51)	or	(56)	+ (52)	60.________
Multifamily High Rise	=	(52)	or	(57)	+ (53)	61.________
In 1,000 ft^2 (or m^2)						
Commercial <50K	=	(53)	or	(58)		62.________
Commercial 50-100K	=	(54)	or	(59)		63.________
Commercial >100K	=	(55)	or	(60)		64.________
Office	=	(56)	or	(61)	+ (54)	65.________
Manufacturing	=	(57)	or	(62)	+ (55)	66.________
Wholesale-warehousing	=	(58)	or	(63)	+ (56)	67.________
Hotels, Motels	=	(59)	or	(64)		68.________
Hospitals	=	(60)	or	(65)		69.________
Cultural Facilities	=	(61)	or	(66)		70.________
Churches	=	(62)	or	(67)		71.________
Educational Facilities	=	(63)	or	(68)		72.________
Recreational Facilities	=	(64)	or	(69)		73.________
In Miles (or km)						
Nonexpressway highway	=	((65)	or	(70))		74.________

*Use of one the two depends on project type. If the major project is residential, obtain values from RLUM-6. If the major project is industrial or office, obtain values from IOLUM-6.

EXHIBIT 7-18

WORKSHEET VMT-1

VEHICLE TRIPS CALCULATION

COMPUTATION SHEET (Numbers in circles indicate previous numbered data entries or computed values.)

Radius

R, Effective radius of study area 1.________

Trip Calculation	2 Amount of Land Use L_i	3 Work Trip Rate T_1	4 Work Trips	5 Other Trip Rate T_2	6 Other Trips (2) x (5)
Single Family Detached			7.		13.
Single Family Attached			8.		14.
Multifamily Low Rise			9.		15.
Multifamily High Rise			10.		16.
Mobile Home			11.		17.
Hotel, Motel			12.		18.
Commercial, <50,000 sq.ft.					
Commercial, 50,000-100,000 sq.ft.					
Commercial >100,000 sq.ft.					
Office					
Manufacturing			19.		21.
Wholesaling-Warehousing			20.		22.
Cultural					
Churches					
Hospitals					
Educational Facilities					
Recreation					
Total Trips			23.________		24.________

EXHIBIT 7-19

WORKSHEET VMT-2

UNCORRECTED VMT

			uncorrected VMT
(23) ______	x L_{work} ______	= 26. ______	VMT^I, work
(23) ______	x L_r (1) ______	= 27. ______	VMT^A, work
(24) ______	x L_{other} ______	= 28. ______	VMT^I, other
(24) ______	x L_r (1) ______	= 29. ______	VMT^A, other

VMT CORRECTION

Total residential work trips = (7) + (8) + (9) + (10) + (11) + (12)	30. ______
Proportion of residential work trips less than (1)	31. ______
Work trips correction = (30) x (31)	32. ______
Work VMT correction = (32) x (1)	33. ______
Total residential other trips = (13) + (14) + (15) + (16) + (17) + (18)	34. ______
Proportion of residential other trips less than (1)	35. ______
Other trips correction = (34) x (35)	36. ______
Other VMT correction = (35) x (1)	37. ______

(26) - (33)	= 38. ______	VMT^I, work
(27) - (33)	= 39. ______	VMT^A, work
(28) - (37)	= 40. ______	VMT^I, other
(29) - (37)	= 41. ______	VMT^A, other

Peak Hour Proportion

proportion of VMT in peak hour	= 42. ______	(Default = .10)
proportion of VMT in off peak hours	= 43. ______	(Default = .90)

Facility Classification

Enter the proportion of distance on each facility for work and other trips.

local streets	44. ______	45. ______
arterials	46. ______	47. ______
expressways	48. ______	49. ______

EXHIBIT 7-20

WORKSHEET VMT-3

IMPACT AREA

(38) ______ x (42) ______ x (44) ______ = ________
(40) ______ x (42) ______ x (45) ______ = ________
50. ______ VMT^I off peak, local streets

(38) ______ x (42) ______ x (46) ______ = ________
(40) ______ x (42) ______ x (47) ______ = ________
51. ______ VMT^I off peak, arterials

(38) ______ x (42) ______ x (48) ______ = ________
(40) ______ x (42) ______ x (49) ______ = ________
52. ______ VMT^I off peak, expressways

(38) ______ x (41) ______ x (44) ______ = ________
(40) ______ x (41) ______ x (45) ______ = ________
53. ______ VMT^I, peak, local streets

(38) ______ x (41) ______ x (46) ______ = ________
(40) ______ x (41) ______ x (47) ______ = ________
54. ______ VMT^I, peak, arterials

(38) ______ x (41) ______ x (48) ______ = ________
(40) ______ x (41) ______ x (49) ______ = ________
55. ______ VMT^I, peak, expressways

AREA OF INFLUENCE

(39) ______ x (42) ______ x (44) ______ = ________
(41) ______ x (42) ______ x (45) ______ = ________
56. ______ VMT^A, off peak, local streets

(39) ______ x (42) ______ x (46) ______ = ________
(41) ______ x (42) ______ x (47) ______ = ________
57. ______ VMT^A, off peak, arterials

(39) ______ x (42) ______ x (48) ______ = ________
(41) ______ x (42) ______ x (49) ______ = ________
58. ______ VMT^A, off peak, expressways

(39) ______ x (41) ______ x (44) ______ = ________
(41) ______ x (41) ______ x (47) ______ = ________
59. ______ VMT^A, peak, local streets

EXHIBIT 7-21

WORKSHEET VMT-4

(39) _____ x (41) _____ x (46) _____ = _______

(41) _____ x (41) _____ x (47) _____ = _______

60. _______ VMT^A, peak, arterials

(39) _____ x (41) _____ x (48) _____ = _______

(41) _____ x (41) _____ x (49) _____ = _______

61. _______ VMT^A, peak, expressways

Vehicle Classification Proportions

Total Manufacturing and Warehousing Trips = (19) + (20) + (21) + (22) = 62. _______

(62) ÷ (23) + (24) = 63. _______

If (63) > 0.07, Then . . . . (63) - .05 = 64. _______

If (63) ≤ 0.07, Then . . . . 64 = 0

0.804 - (64)	= 65. _______	automobile
0.118	= 66. _______	light duty truck, gasoline
0.046 + .8 x (64)	= 67. _______	heavy duty vehicle, gasoline
0.062 + .2 x (64)	= 68. _______	heavy duty vehicle, diesel

Average Route Speeds:	peak	offpeak
local streets	69. _______	72. _______
arterials	70. _______	73. _______
expressways	71. _______	74. _______

EXHIBIT 7-22

WORKSHEET VEM-1

Vehicle Type = 1. ____________ (Gasoline Automobile, Light-Duty Trucks, Heavy-Duty Gasoline Vehicles, Heavy-Duty Diesel Vehicles)

Pollutant = 2. ____________ (Carbon Monoxide, Nitrogen Oxides, Hydrocarbons)

Speed = 3. ____________ mph

Design Year = 4. ____________

Region = 5. ____________ (Low Alt., High Alt., Calif)

Cold Starts = 6. ____________ %, Hot Starts = 7. ____________ %

Ambient Temperature = 8. ____________ °F

10 Vehicle Age (years)	9 Model Year	11 Base Emission Rate C_{ipn}	12 Fraction of Annual Travel m_{in}	13 Speed Correction Factor v_{ips}	14 Ambient Temperature Correction Factor Z_{ipt}	15 Operating Temperature Correction Factor r_{iptws}	16 Model year Emission Contribution e_{ipntwx}	17 Hydro-carbon Crankcase Emissions f_i	18 Hydro-carbon Evaporative Emissions e_i	19 Fraction of Annual Travel m_{in}	20 Model Year Hydro-carbon Emissions e_{HCi}	21 Model Year Total Emissions e_{Ti}
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
>13												

Note: When calculating carbon monoxide and nitrogen oxide emissions, $e_{HCi} = 0$.

Average emission factor 32 ______

EXHIBIT 7- 23

WORKSHEET VEM-2

CALCULATION OF THE COMPOSITE EMISSION FACTOR

Pollutant = 2. ________

Speed = 3. ________ mph

Design Year = 4. ________

Region = 5. ________ (low alt., high alt., Calif.)

Cold Starts = 6. ________ %, Hot starts = 7. ________ %

Ambient Temperature = 8. ________ °F

Vehicle Class	23 Emission Rate	24 Vehicle Class Weighting	25 Product
Automobiles			
Light-duty Trucks			
Heavy-duty Gasoline Vehicles			
Heavy-duty Diesel Vehicles			

Composite emission factor = 26 ________

EXHIBIT 7-24

WORKSHEET EMI-1

LAND USE CATEGORY	1 amount	2 process emission factor	3 process emissions	4 space heating emission factor	5 space heating emissions	6 space cooling emission factor	7 space cooling emissions
residential single family attached							
residential single family detached							
residential mobile homes..........							
residential multifamily low rise...							
residential multifamily high rise..							
commercial <50K....................							
commercial 50-100K................							
commercial >100K..................							
office............................							
wholesale-warehousing.............							
hotels, motels....................							
hospitals.........................							
cultural facilities...............							
churches..........................							
educational facilities............							
recreational facilities...........							
TOTAL EMISSIONS			8. process		9. space-heating		10. space-cooling

manufacturing land use ________ x 18. ________ = 19. ________ (See page 7-18)

EXHIBIT 7-25

WORKSHEET EMI-2

MOTOR VEHICLE EMISSIONS

	12 SPEED	12 VMT	14 EMISSION FACTOR	15 EMISSIONS
VMT^A, off peak, local streets	______	______	______	______
VMT^A, off peak, arterials	______	______	______	______
VMT^A, off peak, expressways	______	______	______	______
VMT^A, peak, local streets	______	______	______	______
VMT^A, peak, arterials	______	______	______	______
VMT^A, peak, expressways	______	______	______	______
		AREA OF INFLUENCE TOTAL 16		______
VMT^I, off peak, local streets	______	______	______	______
VMT^I, off peak, arterials	______	______	______	______
VMT^I, off peak, expressways	______	______	______	______
VMT^I, peak, local streets	______	______	______	______
VMT^I, peak, arterials	______	______	______	______
VMT^I, peak, expressways	______	______	______	______
		IMPACT AREA TOTAL 17		______

EXHIBIT 7-26

WORKSHEET EMI-3

EMISSIONS SUMMARY

		20 PM	21 SOX	22 CO	23 HC	24 NOX	25 Electricity
8	process emissions	______	______	______	______	______	______
9	space heating emissions	______	______	______	______	______	______
10	space cooling emissions	______	______	______	______	______	______
19	industrial emissions	______	______	______	______	______	______
27	STATIONARY SOURCE TOTAL AREA OF INFLUENCE	______	______	______	______	______	26. ______
15	area of influence motor vehicle emissions	______	______	______	______	______	
28	TOTAL, AREA OF INFLUENCE	______	______	______	______	______	
29	26 x emission factor = electric utility emissions	______	______	______	______	______	
16	motor vehicle, impact area emissions	______	______	______	______	______	
30	TOTAL*	______	______	______	______	______	

* Area of influence stationary sources, secondary sources (i.e., electrical generation), and motor vehicle emissions in impact area.

VIII. EXAMPLES OF USE OF COMPUTATION WORKSHEETS

This chapter presents examples of the use of the computation worksheets from the previous chapter. The first section illustrates the use of the land use model worksheets to compute the predicted land use for a residential major project. The second section illustrates the estimation of VMT for the same example case study. The third section illustrates the computation of a motor vehicle emission factor for one pollutant, hydrocarbons. The final section illustrates the emissions computation in the final three worksheets.

A. EXAMPLE OF LAND USE MODEL CALCULATIONS

This section presents an example of the use of the land use model worksheets using data from one of the Residential major projects in this study, namely, Northglenn, Colorado. This planned residential development was initiated in 1960 and completed in 1970 with a final size of 7,000 dwelling units. The worksheets are filled in English units for this example.

The computation of confidence intervals is shown for only one of the projected land uses.

EXHIBIT 8-1

WORKSHEET RLUM -1

RESIDENTIAL LAND USE MODEL VARIABLE DEFINITIONS

AREA OF INFLUENCE

Size of Area of Influence in acres (m^2)	1. 10,000
Number of dwelling units, excluding major project	2. 350
Dwelling units per acre (m^2) = (2) ÷ (1)	3. 0.035
Distance from center of major project to nearest Central Business District in miles (km)	4. 12.2
Projected number of limited-access highway interchanges in 5 years	5. 2
Number of office employees =	6. 0
Office employment per acre (m^2) = (6) ÷ (1)	7. 0
Projected developable land area in 10 years, excluding major project, in acres (m^2)	9. 8,197
Number of manufacturing employees	10. 0
Manufacturing employment per acre (m^2) = (9) ÷ (1)	11. 0
Median income level of families and individuals	12. $6,588
Projected number of acres (m^2) zoned for residential use in 5 years	13. 7,600
Projected percent residential zoned area = (13) ÷ (1)	14. 76

COUNTY

Median income level of families and individuals	15. $6,357
Median income index - area of influence relative to county = (12) ÷ (15)	16. 1.036
Total population	17. 120,246
Projected total population in 10 years	18. 185,789
Area of county in acres (m^2)	19. 796,800
Projected population growth per acre (m^2) = ((18) - (17)) ÷ (19)	20. 0.0823

EXHIBIT 8-2

RESIDENTIAL LAND USE MODEL VARIABLE DEFINITIONS
WORKSHEET RLUM-2

Total employment	21. 40,626
Projected total employment in 10 years	22. 69,284
Projected employment growth per acre (m^2) = ((22) - (21)) ÷ (19)	23. 0.036
Total licensed automobile drivers	24. 35,005
Number of dwelling units	25. 51,457
Auto drivers per dwelling unit = (24) ÷ (25)	26 0.680
Auto drivers per acre (m^2) = (24) ÷ (19)	27. 0.0439

METROPOLITAN AREA

Percent vacant office buildings	28. 7.2
Projected median income level in 2 years	29. $6,740

NEAREST MUNICIPALITY

Projected percent of land which will have public sewerage available in 5 years	30. 100

MAJOR PROJECT

Projected total dwelling units in 2 years	31. 3,006
Projected total dwelling units 2 years before project completion	32. 6,000
Projected total dwelling units of completion	33. 7,000
Projected median income level in 2 years	34. $7,760
Set equal to 1 if (34) ÷ (29) < 0.85	35. 0
Set equal to 1 if a university exists within 3.23 miles (5.20 km) of the center of the major project	36. 0
Projected number of school age children in 2 years	37. 6,900
Schoolage children per dwelling unit = (37) ÷ (31)	38. 2.3
Area of major project in acres (m^2)	39. 1,803

EXHIBIT 8-3

WORKSHEET RLUM-3

Land Use Categories

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
(3) 0.035 x	8910 (3.35E9) 312	656 (2.47E8) 23.0	-400 (-1.50E8) -14			-269 (-1.01E8) -9.42						
(20) 0.0823 x	6790 (2.55E8) 559				40.5 (264000) 3.33							
(4) 12.2 x	-351 (-20300) -4280	-73.7 (-4260) -899	-14.1 (-814) -172		-2.79 (-2.79) -34.0	-11.4 (-658) -139				-4.42 (-255) -53.9	-25.5 (-1470) -311	
(5) 2 x	-1360 (-126000) -2720	-200 (-18600) -400	85.8 (7900) 172			97.1 (9020) 194						
(7) 0 x		791 (2.97E8) 0	845 (3.18E8) 0					191 (7.18E7) 0				
(21) 40,626 x		0.0032 (0.304) 130										
(9) 8197 x		0.0647 (0.00149) 530							0.00175 (4.02E-5) 14.3		0.0408 (9.37E-4) 334	
(23) 0.0360 x			601 (2.26E8) 21.6									
(11) 0 x				1050 (3.95E8) 0								
(26) 0.680 x					-135 (-217) -91.8							

EXHIBIT 8-4

WORKSHEET RLUM-4

Land Use Categories

Variables	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
(16) 1.036 x					46.6 (75.0) 48.3					202 (18800) 209		
(32) 6000 x					0.00595 (0.00957) 35.7							
(33) 7000 x	-0.682 (-63.4) -4770					-0.0736 (-6.84) -515		0.0196 (1.82) 137				
(28) 7.2 x						15.0 (1390) 108						
(14) 76 x							-0.968 (-89.9) -73.6					
(27) 0.0439 x							230 (8.65E7) 10.1					
(35) 0 x							-150 (-13933) 0					
(36) 0 x									60.2 (5590) 0			
(30) 100 x	41.2 (3830) 4120										2.46 (229) 246	

EXHIBIT 8-5

WORKSHEET RLUM-5

Variables	Land Use Categories											
	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	L_{11}	L_{12}
(38) 2.3 x											184 (17100) 423	
(39) 1,803 x												0.103 (417) 186
Σ Columns	-6779	-616	7.6	0	-38.5	-361	-63.5	137	14.3	155	692	186
+ Constant	7200 (669000)	1380 (128000)	355 (33000)	761 (70700)	78.8 (127)	488 (45300)	81.7 (7590)	-23.9 (-2200)	2.54 (236)	-14.7 (-1370)	244 (22700)	-33.5 (-136000)
TOTAL LAND USE	421	764	363	761	40.3	127	18.2	113	16.8	140	936	153

EXHIBIT 8-6

WORKSHEET RLUM-6

RESIDENTIAL LAND USE MODEL

PROJECTED DISAGGREGATION OF LAND USE IN AREA OF INFLUENCE AT PROJECT COMPLETION

Residential		Default Values
Single family detached homes	40. 91	61.
Single family attached homes	41. 1	3.
Mobile homes	42. 1	6.
Multifamily low rise structures	43. 7	29.
Multifamily high rise structures	44. 0	1.

(Note (40) + (41) + (42) + (43) + (44) must = 100)

Commercial		
<50,000 ft^2	45. 39	51.
50-100,000 ft^2	46. 8	20.
>100,000 ft^2	47. 53	29.

(Note (45) + (46) + (47) must = 100)

FINAL PROJECTED LAND USE

In Dwelling Units

Single Family Attached	= (L_1) x (40) ÷ 100	48. 383
Single Family Detached	= (L_1) x (41) ÷ 100	49. 4
Mobile Homes	= (L_1) x (42) ÷ 100	50. 4
Multifamily Low Rise	= (L_1) x (43) ÷ 100	51. 30
Multifamily High Rise	= (L_1) x (44) ÷ 100	52. 0

In 1,000 ft^2 (m^2)

Commercial < 50K	= (L_2) x (45) ÷ 100	53. 298
Commercial 50-100K	= (L_2) x (46) ÷ 100	54. 61
Commercial >100K	= (L_2) x (47) ÷ 100	55. 405
Office	= (L_3)	56. 363

EXHIBIT 8-7

WORKSHEET RLUM-7

RESIDENTIAL LAND USE MODEL

Manufacturing	= L_4	57. 761
Wholesale-Warehousing	= L_6	58. 127
Hotels, Motels	= L_7	59. 18.2
Hospitals	= L_8	60. 113
Cultural Facilities	= L_9	61. 16.8
Churches	= L_{10}	62. 140
Educational Facilities	= L_{11}	63. 936
Recreational Facilities	= L_{12}	64. 153

In miles (km)

Non-expressway highway lane distances	= L_5	65. 403

EXHIBIT 8-8

WORKSHEET LUM-1

CONFIDENCE INTERVALS FOR PREDICTED LAND USE

Final Projected Land Use Category Commercial > 100,000 ft²
corresponds to Dependent Variable Name COMM and General Category L2

PREDICTOR VARIABLE

Name		
OFFACR	1.	0
DISCBD	2.	12.2
DUACRE	3.	0.035
HWYINT	4.	2
EMP60	5.	40,626
VACACR	6.	8197

COMPUTING VARIANCE OF DEPENDENT VARIABLE

(1) x (1) x	Covariance	222973	=	7.	0
(1) x (2) x	Covariance	7339	=	8.	0
(1) x (3) x	Covariance	-20617	=	9.	0
(1) x (4) x	Covariance	23836	=	10.	0
(1) x (5) x	Covariance	-0.0648	=	11.	0
(1) x (6) x	Covariance	1.912	=	12.	0
(2) x (1) x	Covariance	7339	=	13.	0
(2) x (2) x	Covariance	621.2	=	14.	92,459
(2) x (3) x	Covariance	-854.7	=	15.	-365
(2) x (4) x	Covariance	1366	=	16.	33,330
(2) x (5) x	Covariance	-0.002887	=	17.	-1,431
(2) x (6) x	Covariance	0.3710	=	18.	37,101
(3) x (1) x	Covariance	-20617	=	19.	0
(3) x (2) x	Covariance	-854.7	=	20.	-365
(3) x (3) x	Covariance	120777	=	21.	148
(3) x (4) x	Covariance	-23758	=	22.	-1,663
(3) x (5) x	Covariance	-0.06121	=	23.	-87
(3) x (6) x	Covariance	-2.0	=	24.	-573
(4) x (1) x	Covariance	23836	=	25.	0
(4) x (2) x	Covariance	1366	=	26.	33,330
(4) x (3) x	Covariance	-23758	=	27.	-1,663
(4) x (4) x	Covariance	13224	=	28.	52,896
(4) x (5) x	Covariance	0.008156	=	29.	663
(4) x (6) x	Covariance	0.240	=	30.	3,935

EXHIBIT 8-9

WORKSHEET LUM-2

CONFIDENCE INTERVALS FOR PREDICTED LAND USE

COMPUTING VARIANCE OF DEPENDENT VARIABLE

(5) x (1) x Covariance -0.06485	=	31. 0
(5) x (2) x Covariance -0.002889	=	32. -1,431
(5) x (3) x Covariance -0.06121	=	33. -87
(5) x (4) x Covariance 0.008156	=	34. 663
(5) x (5) x Covariance 0.0000006715	=	35. 1,180
(5) x (6) x Covariance 0.00000744	=	36. 2,477
(6) x (1) x Covariance 1.912	=	37. 0
(6) x (2) x Covariance 0.3710	=	38. 37,101
(6) x (3) x Covariance -2.0	=	39. -573
(6) x (4) x Covariance 0.240	=	40. 3,935
(6) x (5) x Covariance 0.00000744	=	41. 2,477
(6) x (6) x Covariance 0.002055	=	42. 138,077

Sum (7) through (42) = 43. 431534

Standard Deviation of Dependent Variable = $\sqrt{(43)}$ 44. 656.9

F - statistic of predictive equation 45. 10.0636

t - statistic of predictive equation = $\sqrt{(45)}$ 46. 3.172

If Final Projected Land Use is Residential or Commercial, set equal to the disaggregation percentage 47. ~~100~~ 53

± Confidence Interval = (46) x (44) x (47) ÷ 100 48. 1,104

EXHIBIT 8-10

WORKSHEET LUM-3

FINAL LAND USE MODEL CALCULATIONS

MAJOR PROJECT

If Residential, total projected dwelling units at project completion, by the following types:

Single-family Detached	49.	7000
Single-family Attached	50.	0
Mobile Homes	51.	0
Multifamily Low Rise	52.	0
Multifamily High Rise	53.	0

If Industrial/Office, total projected land area in 1,000 ft^2 (m^2), by the following types=

Office	54.	—
Manufacturing	55.	—
Wholesale-warehousing	56.	—

TOTAL PROJECTED LAND USE (including Major Project)

In dwelling units	RLUM-6 or IOLUM-6		
Single Family Detached	= ((48) or (53)) + (49)	57.	7,883
Single Family Attached	= ((49) or (54)) + (50)	58.	4
Mobile Homes	= ((50) or (55)) + (51)	59.	4
Multifamily Low Rise	= ((51) or (56)) + (52)	60.	30
Multifamily High Rise	= ((52) or (57)) + (53)	61.	0

In 1,000 ft^2 (m^2)			
Commercial <50K	= ((53) or (58))	62.	298
Commercial 50-100K	= ((54) or (59))	63.	61
Commercial >100K	= ((55) or (60))	64.	405
Office	= ((56) or (61)) + (54)	65.	363
Manufacturing	= ((57) or (62)) + (55)	66.	761
Wholesale-Warehousing	= ((58) or (63)) + (56)	67.	127
Hotels, Motels	= ((59) or (64))	68.	18.2
Hospitals	= ((60) or (65))	69.	113
Cultural Facilities	= ((61) or (66))	70.	16.8
Churches	= ((62) or (67))	71.	140
Educational Facilities	= ((63) or (68))	72.	936
Recreational Facilities	= ((64) or (69))	73.	153

In Miles (km)			
Non-expressway highway lane distances	= ((65) or (70))	74.	40.3

B. EXAMPLE OF TRAFFIC MODEL CALCULATIONS

Using the projected land uses shown on Worksheet LUM-3, page 8-11, the VMT in both the area of influence and impact area are computed. If any development existed in the area of influence in the base year, it would first be subtracted from the values on LUM-3 before they are entered on VMT-1.

1. Worksheet VMT-1

The amount of land use is copied from Worksheet LUM-3 and then multiplied by trip generation rates obtained from Table 5-2.

2. Worksheet VMT-2

The work and other trip lengths are computed via the equations on pages 5-9.

$$L_1 = 0.003 * p^{0.20} * S_1^{1.49}$$

$$L_1 = 0.003 * 1229798^{0.20} * 30^{1.49}$$

$$L_1 = 0.003 * 16.52 * 158.82$$

$$L_1 = 7.87$$

$$L_2 = .5(0.003 * p^{0.18} * S_2^{1.40} + 0.003 * p^{0.26} * S_2^{1.25})$$

$$L_2 = .5(0.003 * 1229798^{0.18} * 30^{1.40} + 0.003 * 1229798^{0.26} * 30^{1.25})$$

$$L_2 = .5(0.003 * 16.52 * 116.94 + 0.003 * 16.52 * 70.21)$$

$$L_2 = .5(5.80 + 3.48)$$

$$L_2 = 4.64$$

The calculation of the corrected VMT is self-explanatory. The default peak hour proportion is used. The facility classifications are calculated using Tables 5-3 and 5-4 as discussed on page 5-13. Rounding off the trip lengths calculated previously to eight and five miles respectively, the example on page 5-16 is appropriate.

3. Worksheet VMT-3 and VMT-4

The calculations, though tedious, are self explanatory. The default average route speeds discussed on page 5-18 are employed.

EXHIBIT 8-11

WORKSHEET VMT-1

VEHICLE TRIPS CALCULATION

COMPUTATION SHEET (Numbers in circles indicate previous numbered data entries or computed values.)

Radius

R, Effective radius of study area 1. 2.23

Trip Calculation	2 Amount of Land Use L_j	3 Work Trip Rate T_i	4 Work Trips	5 Other Trip Rate T_2	6 Other Trips (2) x (5)
Single Family Detached	7833	1.8	7. 14099	9	13. 70497
Single Family Attached	4	1.5	8. 6	7	14. 28
Multifamily Low Rise	30	1.2	9. 36	6	15. 180
Multifamily High Rise	0	0.8	10. 0	4	16. 0
Mobile Home	4	1.8	11. 7	5	17. 20
Hotel, Motel	18.2	0.4	12. 7	10	18. 182
Commercial, <50,000 sq.ft.	298	0	0	130	38740
Commercial, 50,000-100,000 sq.ft.	61	0	0	80	4880
Commercial >100,000 sq.ft.	405	0	0	40	16200
Office	363	16	5808	0	0
Manufacturing	761	5	19. 3805	0	21. 0
Wholesaling-Warehousing	127	4	20. 508	0	22. 0
Cultural	16.8	0	0	2	34
Churches	140	0	0	2	280
Hospitals	113	16	1808	0	0
Educational Facilities	936	0		4	3744
Recreation	153	0		10	1530

Total Trips 23. 26084 24. 136314

EXHIBIT 8-12

WORKSHEET VMT-2

UNCORRECTED VMT

uncorrected VMT

(23) 26084 x L_{work} 7.87 = 26. 205281 VMT^I, work

(23) 26084 x L_r (1) 2.23 = 27. 58167 VMT^A, work

(24) 136314 x L_{other} 4.64 = 28. 632497 VMT^I, other

(24) 136314 x L_r (1) 2.23 = 29. 303980 VMT^A, other

VMT CORRECTION

Total residential work trips = (7) + (8) + (9) + (10) + (11) + (12) — 30. 14155

Proportion of residential work trips less than (1) — 31. .40

Work trips correction = (30) x (31) — 32. 5662

Work VMT correction = (32) x (1) — 33. 12626

Total residential other trips = (13) + (14) + (15) + (16) + (17) + (18) — 34. 70907

Proportion of residential other trips less than (1) — 35. .40

Other trips correction = (34) x (35) — 36. 28362

Other VMT correction = (35) x (1) — 37. 63249

(26) - (33) = 38. 192655 VMT^I, work

(27) - (33) = 39. 45541 VMT^A, work

(28) - (37) = 40. 569248 VMT^I, other

(29) - (37) = 41. 240731 VMT^A, other

Peak Hour Proportion

- proportion of VMT in peak hour = 42. .10 (Default = .10)
- proportion of VMT in off peak hours = 43. .90 (Default = .90)

Facility Classification

Enter the proportion of distance on each facility for work and other trips.

	Work	Other
local streets	44. .06	45. .10
arterials	46. .38	47. .58
expressways	48. .56	49. .32

EXHIBIT 8-13

WORKSHEET VMT-3

IMPACT AREA

(38) 192655 x (42) .90 x (44) .06 = 10403

(40) 569248 x (42) .90 x (45) .10 = 51232

50. 61635 VMT^I off peak, local streets

(38) 192655 x (42) .90 x (46) .38 = 65888

(40) 569248 x (42) .90 x (47) .58 = 297147

51. 363,035 VMT^I off peak, arterials

(38) 192655 x (42) .90 x (48) .56 = 97098

(40) 569248 x (42) .90 x (49) .32 = 163943

52. 261041 VMT^I off peak, expressways

(38) 192655 x (41) .10 x (44) .06 = 1156

(40) 569248 x (41) .10 x (45) .10 = 5692

53. 6848 VMT^I, peak, local streets

(38) 192655 x (41) .10 x (46) .38 = 7321

(40) 569248 x (41) .10 x (47) .58 = 33016

54. 40337 VMT^I, peak, arterials

(38) 192655 x (41) .10 x (48) .56 = 10789

(40) 569248 x (41) .10 x (49) .32 = 18216

55. 29005 VMT^I, peak, expressways

AREA OF INFLUENCE

(39) 45541 x (42) .90 x (44) .06 = 2459

(41) 240731 x (42) .90 x (45) .10 = 21666

56. 24125 VMT^A, off peak, local streets

(39) 45541 x (42) .90 x (46) .38 = 15575

(41) 240731 x (42) .90 x (47) .58 = 125662

57. 141237 VMT^A, off peak, arterials

(39) 45541 x (42) .90 x (48) .56 = 22953

(41) 240731 x (42) .90 x (49) .32 = 69330

58. 92283 VMT^A, off peak, expressways

(39) 45541 x (41) .10 x (44) .06 = 273

(41) 240731 x (41) .10 x (47) .10 = 2407

59. 2680 VMT^A, peak, local streets

EXHIBIT 8-14

WORKSHEET VMT-4

(39) 45541 x (41) .10 x (46) .38 = 1730

(41) 240731 x (41) .10 x (47) .58 = 13962

60. 15692 VMT^A, peak, arterials

(39) 45541 x (41) .10 x (48) .56 = 2550

(41) 240731 x (41) .10 x (49) .32 = 7703

61. 10253 VMT^A, peak, expressways

Vehicle Classification Proportions

Total Manufacturing and Warehousing Trips = 19 + 20 + 21 + 22 = 62. 4313

62 ÷ 23 + 24 = 63. .03

If 63 > 0.07, Then . . . . 63 - .05 = 64. ____

If 63 ≤ 0.07, Then . . . . 64 = 0 ✓

0.804 - 64	= 65. .804	automobile
0.118	= 66. .118	light duty truck, gasoline
0.046 + .8 x 64	= 67. .046	heavy duty vehicle, gasoline
0.062 + .2 x 64	= 68. .062	heavy duty vehicle, diesel

Average Route Speeds:	peak	offpeak
local streets	69. 37	72. 50
arterials	70. 20	73. 28
expressways	71. 15	74. 18

C. EXAMPLE OF CALCULATION OF MOTOR VEHICLE EMISSION FACTORS

An example of calculation of a composite motor vehicle emission factor is presented in this section. An effort has been made to present an example which represents a typical situation but requires explicit calculation of each of the factors.

The composite emission factor to be evaluated is that for hydrocarbons during the design year 1985 for vehicles operating in Boston, Massachusetts. The emission factor will be calculated for a speed of 30 miles per hour, 30 percent of the vehicles are operating from cold start, and 40 percent are operating from hot start.* The mean ambient temperature during this period is 50°F. The first step is to calculate the emission factor for each vehicle type using Worksheet VEM-1 four times (i.e., one for each vehicle type).

1. Automobiles

- Fill in lines 1 through 8 using the information stated in the problem, placing automobiles (GA) on line 1.
- Fill in column 9 with the model year corresponding to each vehicle age. 1985 is put next to Age=1, 1984 is inserted next to Age=2, down to 1973 next to Age≥13.
- Locate the correct table of base emission rates (C_{ipn}) in Appendix D of AP-42 corresponding to the information on lines 1, 4 and 5. The correct table is D1.17. Fill in column 11 with the appropriate hydrocarbon base emission rate (in grams/mile).
- Put in column 12 the proportion of VMT traveled by each vehicle model year in 1985. For this example, the national mix presented in Table D1.22 has been used.
- Calculate the speed correction factor to represent 30 mph using Table D1.23. Examination of the model years (column 9) indicates that all vehicles being considered were produced after 1970. Thus, a single speed correction factor is appropriate. This is:

---

*That is, 30 percent of the currently running vehicles have just started cold, 40 percent hot, and 30 percent have not recently started.

$$V = \exp [0.942-0.0592(30) + 0.000567(30)^2]$$
$$= 0.72$$

This factor is inserted in column 13 for all model years.

- The effects of operating the vehicle at an ambient temperature of 50°F instead of the FTP range of 68°-86° is calculated using the equation in Table D1.25. It is being assumed that all post-1974 automobiles are to be equipped with catalytic convertors. Thus, separate correction factors must be calculated for 1973-1974 and for 1975-1985. These factors are:

$$Z_{pre-1975} = -0.0113(50) + 1.81$$
$$= 1.24$$

$$Z_{post-1974} = -0.0304(50) + 3.25$$
$$= 1.73$$

These values are inserted with the proper model years in column 14.

Calculation of the operating temperature correction factor involves use of equations D1-2 and D1-3 plus Table D1.25. Again, it is necessary to segregate by catalyst and noncatalyst cars.

Noncatalyst cars (pre-1975)

$$r = \frac{30 + 70\ f(t)}{20 + 80\ f(t)}$$

$$f(t) = 0.0079\ (50) + 0.03$$
$$= 0.425$$

thus,

$$r_{pre-1975} = 1.11$$

Catalyst cars (post-1974)

$$r = \frac{30 + 40\ f(t) + 30\ g(t)}{20 + 27\ f(t) + 53\ g(t)}$$

$$f(t)_{catalyst} = 0.0050\ (50) - 0.0409$$
$$= 0.2091$$

$$G(t)_{catalyst} = 0.0018\ (50) + 0.0095$$
$$= 0.0995$$

$$r_{catalyst} = 1.34$$

These values are inserted with the appropriate model years in column 15.

- For each model year, multiply columns 11, 12, 13, 14, and 15 together and put the result in column 16.
- Fill in crankcase hydrocarbon emissions (column 17) from Table D1.26. As all model years being considered are post-1967, this factor is 0.0 for all model years.
- Using Table D1.27, evaporative hydrocarbon emissions can be determined for each model year. These are:

Model Year	Emission (g/mi)
Post-1979	0.5
1973-1979	1.76

These values are inserted in column 18.

- Column 12 is copied to column 19.
- Columns 17 and 18 are added and the result is multiplied by column 19. The result is placed in column 20. For model year 1985 this is:

$$(\text{col } 20) = (0.0 + 0.5)\ (0.112)$$
$$= 0.056$$

- Columns 16 and 20 are added and the result put in column 21. For model year 1975:

$$(\text{col } 21) = 0.05 + 0.056$$
$$= 0.106$$

- The contributions of each model year to the total emissions (column 21) is summed and the result, 2.15 gr/mi, is placed on line 22. This completes calculation of the automobile emission factor.

2. <u>Light-Duty Trucks</u>

- Using a new VEM-1, put light-duty trucks (LDT) on line 1.
- Fill in lines 2 through 8 and column 9 identically to the automobile worksheet
- Use Table D2.9 to fill in column 11 and Table D2.11 to fill in column 12.
- Speed, ambient temperature and operating temperature correction factors for LDT are identical to those for automobiles.

Complete columns 13, 14, and 15 similarily to the respective columns on the automobile worksheet.

- Compute column 16 by multiplying columns 11 through 15 together for each model year.
- Fill in crankcase and evaporative emissions (columns 17 and 18) by model year using Table D2.15.
- Copy column 12 to column 19; add columns 17 and 18 and multiply the sum by column 19. Put the result in column 20.
- Add columns 16 and 20 for each model year; insert the result in column 21. Add column 21 and put the sum on line 22. This is the LDT hydrocarbon emission factor.

3. Heavy-Duty Gasoline Vehicles (HDG)

- On a new VEM-1, write HDV on line 1 and again copy lines 2 through 8 and column 9 from the automobile worksheet.
- Fill in the base emission factors (column 11) from Table D4.10. Fill in the model year mix (column 12) from Table D4.11.
- Determine the speed correction factor, v_{ips}, using Table D4.12. This is determined as follows:

  $$v = \exp(1.07 - 0.0663 (30) + 0.000598 (30)^2)$$

  $$v = 0.68$$

  This value should be placed in column 13.
- The ambient and operating temperature correction factors for HDG is 1.0. This value is placed in columns 14 and 15 for each model year.
- Multiply columns 11 through 15; insert the result in column 16 for each model year.
- Fill in columns 17 and 18 using Table D4.14. Note that a 50 percent reduction in evaporative emissions is assumed after 1978.
- Copy column 12 to 19. Calculate the HDG hydrocarbon emission rate (line 22) similarly to the LDT calculation.

4. Heavy-Duty Diesel (HDD)

- Put HDD on line 1, compute lines 2 through 8 and column 9 as was done on the other worksheets.

- Fill in the hydrocarbon base emission rate using Table Table D5.1. This number is constant for all model years.
- Use Table D5.2 to complete column 12.

  Use equation D5.3 and Table D5.3 to compute v_{ips}.

  $$v = \frac{18}{42(30)} \quad \frac{[(60-30)\ (1.38) + (30-18)(2.25)]}{1.38}$$

  $$= 0.71$$

  This value should be inserted in column 13.
- Columns 14 and 15 are 1.0 for HDD.
- Calculate column 16 for each model year by multiplying columns 11 through 15.
- Columns 17 and 18 are 0.0 for HDD.
- Line 22 thus becomes the summation of column 16.

5. Calculation of Composite Emission Rate

- To calculate the composite emission factor, worksheet VEM-2 should be used.
- Fill in lines 2 through 8 as it was done on VEM-1
- In column 23, write the final emission rate (line 22 of VEM-1) for each vehicle type.
- Insert in column 24, the mix of vehicle types by class. In this example, a nationwide mix presented in Chapter D7.1 of AP-42 has been used.
- Multiply columns 23 by 24 and insert the product in column 25 for each vehicle class.
- Line 26 is the sum of column 25. This is the final composite hydrocarbon emission rate.

EXHIBIT 8-15

WORKSHEET VEM-1

Vehicle Type = 1. GA (GA, LDT, HDG, HDD)
Pollutant = 2. HC (CO, NOX, HC)
Speed = 3. 30 mph
Design Year = 4. 1985
Region = 5. Low Alt (Low Alt., High Alt., Calif)
Cold Starts = 6. 30 %, Hot Starts = 7. 40 %
Ambient Temperature = 8. 50 °F

10 Vehicle Age (years)	9 Model Year	11 Base Emission Rate c_{ipn}	12 Fraction of Annual Travel m_{in}	13 Speed Correction Factor v_{ips}	14 Ambient Temperature Correction Factor z_{ipt}	15 Operating Temperature Correction Factor r_{iptws}	16 Model year Emission Contribution e_{ipntwx}	17 Hydro-carbon Crankcase Emissions f_i	18 Hydro-carbon Evaporative Emissions e_i	19 Fraction of Annual Travel m_{in}	20 Model Year Hydro-carbon Emissions e_{HCi}	21 Model Year Total Emissions e_{Ti}
1	1985	0.27	0.112	0.72	1.73	1.34	0.05	0.0	0.50	0.112	0.06	0.11
2	1984	0.32	0.143	0.72	1.73	1.34	0.08	0.0	0.50	0.143	0.07	0.15
3	1983	0.38	0.130	0.72	1.73	1.34	0.08	0.0	0.50	0.130	0.07	0.15
4	1982	0.43	0.121	0.72	1.73	1.34	0.09	0.0	0.50	0.121	0.06	0.15
5	1981	0.49	0.108	0.72	1.73	1.34	0.09	0.0	0.50	0.108	0.05	0.14
6	1980	0.54	0.094	0.72	1.73	1.34	0.08	0.0	0.50	0.094	0.05	0.13
7	1979	0.59	0.079	0.72	1.73	1.34	0.08	0.0	1.76	0.079	0.14	0.22
8	1978	0.65	0.063	0.72	1.73	1.34	0.07	0.0	1.76	0.063	0.11	0.18
9	1977	2.60	0.047	0.72	1.73	1.34	0.20	0.0	1.76	0.047	0.08	0.28
10	1976	2.80	0.032	0.72	1.73	1.34	0.15	0.0	1.76	0.032	0.06	0.21
11	1975	3.00	0.019	0.72	1.73	1.34	0.09	0.0	1.76	0.019	0.03	0.12
12	1974	6.20	0.013	0.72	1.24	1.11	0.08	0.0	1.76	0.013	0.02	0.10
>13	1973	6.20	0.039	0.72	1.24	1.11	0.24	0.0	1.76	0.039	0.07	0.31

Note: When calculating carbon monoxide and nitrogen oxide emissions, e_{HCi} = 0.

Average emission factor 22 2.15

EXHIBIT 8-16

WORKSHEET VEM-1

Vehicle Type = 1. LDT (GA, LDT, HDG, HDD)

Pollutant = 2. HC (CO, NOX, HC)

Speed = 3. 30 mph

Design Year = 4. 1985

Region = 5. Low Alt (Low Alt., High Alt., Calif)

Cold Starts = 6. 30 %, Hot Starts = 7. 40 %

Ambient Temperature = 8. 50 °F

10 Vehicle Age (years)	9 Model Year	11 Base Emission Rate c_{ipn}	12 Fraction of Annual Travel m_{in}	13 Speed Correction Factor v_{ips}	14 Ambient Temperature Correction Factor z_{ipt}	15 Operating Temperature Correction Factor r_{iptws}	16 Model year Emission Contribution e_{ipntwx}	17 Hydrocarbon Crankcase Emissions f_i	18 Hydrocarbon Evaporative Emissions e_i	19 Fraction of Annual Travel m_{in}	20 Model Year Hydrocarbon Emissions e_{HCi}	21 Model Year Total Emissions e_{Ti}
1	1985	1.0	0.094	0.72	1.73	1.34	0.16	0.0	0.5	0.094	0.05	0.20
2	1984	1.2	0.141	0.72	1.73	1.34	0.28	0.0	0.5	0.141	0.07	0.35
3	1983	1.4	0.132	0.72	1.73	1.34	0.31	0.0	0.5	0.132	0.07	0.38
4	1982	1.6	0.123	0.72	1.73	1.34	0.33	0.0	0.5	0.123	0.06	0.39
5	1981	1.8	0.098	0.72	1.73	1.34	0.29	0.0	0.5	0.098	0.05	0.34
6	1980	2.0	0.083	0.72	1.73	1.34	0.28	0.0	0.5	0.083	0.04	0.32
7	1979	2.2	0.076	0.72	1.73	1.34	0.28	0.0	3.1	0.076	0.23	0.51
8	1978	2.4	0.057	0.72	1.73	1.34	0.23	0.0	3.1	0.057	0.18	0.41
9	1977	5.1	0.044	0.72	1.73	1.34	0.37	0.0	3.1	0.044	0.14	0.51
10	1976	5.4	0.032	0.72	1.73	1.34	0.29	0.0	3.1	0.032	0.10	0.39
11	1975	5.7	0.023	0.72	1.73	1.34	0.21	0.0	3.1	0.023	0.07	0.28
12	1974	7.6	0.016	0.72	1.24	1.11	0.12	0.0	3.1	0.016	0.05	0.17
>13	1973	7.6	0.081	0.72	1.24	1.11	0.61	0.0	3.1	0.081	0.25	0.86

Note: When calculating carbon monoxide and nitrogen oxide emissions, $e_{HCi} = 0$.

Average emission factor 22 5.11

EXHIBIT 8-17

WORKSHEET VEM-1

Vehicle Type = 1. HDG (GA, LDT, HDG, HDD)
Pollutant = 2. HC (CO, NOX, HC)
Speed = 3. 30 mph
Design Year = 4. 1985
Region = 5. Low Alt (Low Alt., High Alt., Calif)
Cold Starts = 6. 30 %, Hot Starts = 7. 40 %
Ambient Temperature = 8. 50 °F

10 Vehicle Age (years)	9 Model Year	11 Base Emission Rate c_{ipn}	12 Fraction of Annual Travel m_{in}	13 Speed Correction Factor v_{ips}	14 Ambient Temperature Correction Factor z_{ipt}	15 Operating Temperature Correction Factor r_{iptws}	16 Model year Emission Contribution e_{ipntwx}	17 Hydro-carbon Crankcase Emissions f_i	18 Hydro-carbon Evaporative Emissions e_i	19 Fraction of Annual Travel m_{in}	20 Model Year Hydro-carbon Emissions e_{HCi}	21 Model Year Total Emissions e_{Ti}
1	1985	6.0	0.062	0.68	1.0	1.0	0.25	0.0	2.9	0.062	0.18	0.43
2	1984	6.1	0.124	0.68	1.0	1.0	0.51	0.0	2.9	0.124	0.36	0.87
3	1983	6.1	0.117	0.68	1.0	1.0	0.49	0.0	2.9	0.117	0.34	0.83
4	1982	6.1	0.110	0.68	1.0	1.0	0.46	0.0	2.9	0.110	0.32	0.78
5	1981	6.2	0.093	0.68	1.0	1.0	0.39	0.0	2.9	0.093	0.27	0.66
6	1980	6.2	0.080	0.68	1.0	1.0	0.34	0.0	2.9	0.080	0.23	0.57
7	1979	6.2	0.066	0.68	1.0	1.0	0.28	0.0	2.9	0.066	0.19	0.47
8	1978	6.3	0.057	0.68	1.0	1.0	0.24	0.0	5.8	0.057	0.33	0.57
9	1977	13.9	0.047	0.68	1.0	1.0	0.44	0.0	5.8	0.047	0.27	0.71
10	1976	14.0	0.040	0.68	1.0	1.0	0.38	0.0	5.8	0.040	0.23	0.61
11	1975	14.0	0.031	0.68	1.0	1.0	0.30	0.0	5.8	0.031	0.18	0.48
12	1974	14.0	0.021	0.68	1.0	1.0	0.20	0.0	5.8	0.021	0.12	0.32
>13	1973	14.4	0.153	0.68	1.0	1.0	1.50	0.0	5.8	0.153	0.89	2.39

Note: When calculating carbon monoxide and nitrogen oxide emissions, e_{HCi} = 0.

Average emission factor 22 9.69

EXHIBIT 8-18

WORKSHEET VEM-1

Vehicle Type = 1. HDD (GA, LDT, HDG, HDD)

Pollutant = 2. HC (CO, NOX, HC)

Speed = 3. 30 mph

Design Year = 4. 1985

Region = 5. Low Alt (Low Alt., High Alt., Calif)

Cold Starts = 6. 30 %, Hot Starts = 7. 40 %

Ambient Temperature = 8. 50 °F

10 Vehicle Age (years)	9 Model Year	11 Base Emission Rate C_{ipn}	12 Fraction of Annual Travel m_{in}	13 Speed Correction Factor v_{ips}	14 Ambient Temperature Correction Factor Z_{ipt}	15 Operating Temperature Correction Factor r_{iptws}	16 Model year Emission Contribution e_{ipntwx}	17 Hydro-carbon Crankcase Emissions f_i	18 Hydro-carbon Evaporative Emissions e_i	19 Fraction of Annual Travel m_{in}	20 Model Year Hydro-carbon Emissions e_{HCi}	21 Model Year Total Emissions e_{T_i}
1	1985	4.6	0.096	0.71	1.0	1.0	0.31	0.0	0.0		0.0	0.31
2	1984	4.6	0.169	0.71	1.0	1.0	0.55	0.0	0.0		0.0	0.55
3	1983	4.6	0.168	0.71	1.0	1.0	0.55	0.0	0.0		0.0	0.55
4	1982	4.6	0.164	0.71	1.0	1.0	0.53	0.0	0.0		0.0	0.53
5	1981	4.6	0.110	0.71	1.0	1.0	0.36	0.0	0.0		0.0	0.36
6	1980	4.6	0.080	0.71	1.0	1.0	0.26	0.0	0.0		0.0	0.26
7	1979	4.6	0.067	0.71	1.0	1.0	0.22	0.0	0.0		0.0	0.22
8	1978	4.6	0.048	0.71	1.0	1.0	0.16	0.0	0.0		0.0	0.16
9	1977	4.6	0.034	0.71	1.0	1.0	0.11	0.0	0.0		0.0	0.11
10	1976	4.6	0.018	0.71	1.0	1.0	0.06	0.0	0.0		0.0	0.06
11	1975	4.6	0.011	0.71	1.0	1.0	0.04	0.0	0.0		0.0	0.04
12	1974	4.6	0.007	0.71	1.0	1.0	0.02	0.0	0.0		0.0	0.02
>13	1973	4.6	0.029	0.71	1.0	1.0	0.09	0.0	0.0		0.0	0.09

Note: When calculating carbon monoxide and nitrogen oxide emissions, e_{HCi} = 0.

Average emission factor 22 3.26

EXHIBIT 8-19

WORKSHEET VEM-2

CALCULATION OF THE COMPOSITE EMISSION FACTOR

Pollutant = 2. HC

Speed = 3. 30 mph

Design Year = 4. 1985

Region = 5. low alt (low alt., high alt., Calif.)

Cold Starts = 6. 30 %, Hot starts = 7. 40 %

Ambient Temperature = 8. 50 °F

Vehicle Class	23 Emission Rate	24 Vehicle Class Weighting	25 Product
Automobiles	2.15	0.804	1.73
Light-duty Trucks	5.11	0.118	0.60
Heavy-duty Gasoline Vehicles	9.69	0.046	0.45
Heavy-duty Diesel Vehicles	3.26	0.032	0.10

Composite emission factor = 26 2.88

D. CALCULATION OF EMISSIONS

This section continues with the Northglenn, Colorado, case as an example. Only the emissions of nitrogen oxides are computed, calculations of the emissions of the other criteria pollutants would be analogous. Assur all stationary source energy demands are met by gas or electricity.

1. Worksheet No. EMI-1

The worksheet is filled out twice, once for gas combustion and once for electricity consumption.

- The amount of land use is copies from worksheet LUM-3,
- The process emission factors are copied from the tables in Chapter 4,
- The spaceheating emission factor is copied from the same tables. Before entry, it is multiplied by the number of degree days in Northglenn as estimated from Figure 4-1. (e.g., in the case of residential single family detached, this would be

$$2.6 \times 10^{-3} \frac{\text{pounds}}{\text{dwelling unit-ht.d.d.}} * 6750 \text{ degree days}$$

$$= \text{pounds/dwelling unit}),$$

- The space cooling emission factor is computed in an analogous manner,
- The industrial floor area is assumed to be entirely composed of SIC36.

2. Worksheet No. EMI-2

The motor vehicle traffic values are copied from worksheet VMT-3 and VMT-4.

For the purposes of this example, a set of emission factors were computed from AP-42 [8] using the 1972 national mix NO_x emission rate for low altitude and 19.6 mph. A speed correction was applied using the light duty speed correction equations and extrapolation to high altitude was made using a ratio derived from Table 3.1.2-3 [8].

3. Worksheet No. EMI-3

Emissions on worksheets EMI-1 and EMI-2 are copied on worksheet EMI-3. Emissions from electrical consumption, line 26, is computed by multiplying line 26 by the appropriate emission factor from Table 4-1.

EXHIBIT 8-20

WORKSHEET EMI-1

Pollutant NOX

Heating degree days ________ Cooling degree days ________ Operating Hours ________

LAND USE CATEGORY	1 amount	2 process emission factor	3 process emissions	4 space heating emission factor	5 space heating emissions	6 space cooling emission factor	7 space cooling emissions
residential single family attached	7383	0		17.55	129571	0	
residential single family detached	4	0		17.55	70	0	
residential mobile homes	4	0		11.48	46	0	
residential multifamily low rise...	30	0		8.10	243	0	
residential multifamily high rise..	0	0		6.75	0	0	
commercial <50K..................	298	0		30	8940	0	
commercial 50-100K...............	61	0		30	1830	0	
commercial >100K.................	405	0		30	12150	0	
office...........................	363	0		0	0	0	
wholesale-warehousing............	127	0		30	3810	0	
hotels, motels...................	18	0		10	180	0	
hospitals........................	113	0		10	1130	0	
cultural facilities..............	17	0		10	170	0	
churches.........................	140	0		10	1400	0	
educational facilities...........	936			10	9360		
recreational facilities..........	153						
TOTAL EMISSIONS			8. 0 (process)		9. 168900 lbs (space-heating)		10. 0 (space-cooling)

manufacturing land use 761 x 18. 56 = 19. ________

EXHIBIT 8-21

WORKSHEET EMI-1

LAND USE CATEGORY	1 amount	2 process emission factor	3 process emissions	4 space heating emission factor	5 space heating emissions	6 space cooling emission factor	7 space cooling emissions
residential single family attached	7383	25400	1.9×10^8	0		1880	1.4×10^7
residential single family detached	4	25400	1.0×10^5	0		1880	7.5×10^3
residential mobile homes..........	4	24400	9.8×10^4	0		1360	5.4×10^3
residential multifamily low rise...	30	19200	5.8×10^5	0		600	1.8×10^4
residential multifamily high rise..	0	15900	0	0		600	0
commercial <50K....................	298	23000	6.9×10^6	0		3,120	9.3×10^5
commercial 50-100K.................	61	23000	1.4×10^6	0		3,120	1.9×10^5
commercial >100K...................	405	23000	9.3×10^6	0		3,120	1.3×10^6
office.............................	363	28000	1.0×10^7	12825	4.6×10^6	.900	3.3×10^5
wholesale-warehousing..............	127	23000	2.9×10^6	0		3,120	4.0×10^5
hotels, motels.....................	18	12000	2.2×10^6	0		280	5.0×10^3
hospitals..........................	113	43000	4.9×10^6	0		3,540	4.0×10^5
cultural facilities................	17	12000	2.0×10^6	0		.350	6.0×10^3
churches...........................	140	4200	5.9×10^5	0		2.280	3.2×10^5
educational facilities.............	936	7190	6.6×10^6	0		.280	2.6×10^5
recreational facilities............	153	—		—		—	
TOTAL EMISSIONS			8. 2.3×10^8 kWh process		9. 4.6×10^6 kWh space-heating		10. 1.8×10^7 space-cooling

manufacturing land use 17. 761 x 18. 56000 = 19. 4.3×10^7

EXHIBIT 8-22

WORKSHEET EMI-2

MOTOR VEHICLE EMISSIONS

Pollutant: NOX

	SPEED	12 VMT	14 EMISSION FACTOR	15 EMISSIONS
VMT^A, off peak, local streets	50	24125	4.7	1.1×10^5
VMT^A, off peak, arterials	28	141237	3.6	5.1×10^5
VMT^A, off peak, expressways	18	92283	3.1	2.9×10^5
VMT^A, peak, local streets	37	2680	4.0	1.1×10^4
VMT^A, peak, arterials	20	15692	3.3	5.2×10^4
VMT^A, peak, expressways	15	10253	3.0	3.1×10^4
			AREA OF INFLUENCE TOTAL 16	1.0×10^6 grams
VMT^I, off peak, local streets	50	61635	4.7	2.9×10^5
VMT^I, off peak, arterials	28	363035	3.6	1.3×10^6
VMT^I, off peak, expressways	18	261041	3.1	8.1×10^5
VMT^I, peak, local streets	37	6848	4.0	2.7×10^4
VMT^I, peak, arterials	20	40337	3.3	1.3×10^5
VMT^I, peak, expressways	15	29005	3.0	8.7×10^4
			IMPACT AREA TOTAL 17	2.7×10^6

EXHIBIT 8-23

WORKSHEET EMI-3

EMISSIONS SUMMARY

		20 PM	21 SOX	22 CO	23 HC	24 NOX	25 Electricity
8	process emissions					0	2.3×10^8
9	space heating emissions					168,900	4.6×10^6
10	space cooling emissions					0	1.8×10^7
19	industrial emissions					43,000	4.3×10^7
27	STATIONARY SOURCE TOTAL AREA OF INFLUENCE					2.1×10^5 lbs./yr	26. 3.0×10^8 kwh/yr
15	area of influence motor vehicle emissions					7.9×10^5	
28	TOTAL, AREA OF INFLUENCE					1.0×10^6 lbs/yr.	
29	26 x emission factor = electric utility emissions					6.6×10^6	
16	motor vehicle, impact area emissions					2.1×10^6	
30	TOTAL*					8.9×10^6 lbs/yr.	

* Area of influence stationary sources, secondary sources (i.e., electrical generation), and motor vehicle emissions in impact area.

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APPENDIX A

STATISTICAL OUTPUT FOR THE PREDICTIVE LAND USE EQUATIONS

1. RESIDENTIAL MODEL

EQUATION 1.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: RES

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DUACRE	8905.83	2602.95	3.42143
DELP2	6785.85	2576.30	2.63395
DISCBD	-350.874	141.187	-2.48518
HWYINT	-1358.69	766.921	-1.77162
SEWER	41.1915	25.4075	1.62123
MPR70	-.681883	.472902	-1.44191
C	7204.98	4174.30	1.72603

R-SQUARED = .7217

LOG OF LIKELIHOOD FUNCTION = -189.311

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.3634

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .195094+09

STANDARD ERROR OF THE REGRESSION = 3873.91

SUM OF RESIDUALS = .146484-02

MEAN VALUE OF DEPENDENT VARIABLE = 4784.90

F-STATISTIC(6., 13.) = 5.61987

1. RESIDENTIAL MODEL

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DUACRE	DELP2	DISCBD	HWYINT	SEWER	MPR70
DUACRE	.677537+07	-353084.	18017.8	-.118080+07	14836.0	17.7991
DELP2	-353084.	.663732+07	-69404.6	110192.	16535.0	475.734
DISCBD	18017.8	-69404.6	19933.7	32323.0	504.143	-5.33587
HWYINT	-.118080+07	110192.	32323.0	588167.	-809.247	-8.98286
SEWER	14836.0	16535.0	504.143	-809.247	645.541	-.951074
MPR70	17.7991	475.734	-5.33587	-8.98286	-.951074	.223637
C	-.196117+07	-.389661+07	-407154.	-863813.	-55546.9	-752.193
	1	2	3	4	5	6

	C
DUACRE	-.196117+07
DELP2	-.389661+07
DISCBD	-407154.
HWYINT	-863813.
SEWER	-55546.9
MPR70	-752.193
C	.174248+08
	7

```
LINE  4.
        SMPL

SMPL =      1.    4.    6.    9.   13.   13.   18.   18.
LINE  5.
        OLSQ
```

EQUATION 2.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: COMM

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
OFFACR	790.700	472.200	1.67450
DISCBD	-73.6968	24.9239	-2.95687
DUACRE	655.610	347.530	1.88648
HWYINT	-200.069	114.997	-1.73977
EMP60	.327286-02	.845695-03	3.87003
VACACR	.647417-01	.453333-01	1.42813
C	1376.49	731.164	1.88260

R-SQUARED = .8228

LOG OF LIKELIHOOD FUNCTION = -149.006

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.3607

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .346576+07

STANDARD ERROR OF THE REGRESSION = 516.330

SUM OF RESIDUALS = .188470-03

MEAN VALUE OF DEPENDENT VARIABLE = 1044.60

F-STATISTIC(6., 13.) = 10.0636

1. RESIDENTIAL MODEL

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	OFFACR	DISCBD	DUACRE	HWYINT	EMP60	VACACR
OFFACR	222973.	7338.67	-20616.9	23835.7	-.648491-01	1.91226
DISCBD	7338.67	621.200	-854.726	1366.15	-.288654-02	.370956
DUACRE	-20616.9	-854.726	120777.	-23758.1	-.612073-01	-1.99969
HWYINT	23835.7	1366.15	-23758.1	13224.4	.815642-02	.240051
EMP60	-.648491-01	-.288654-02	-.612073-01	.815642-02	.715200-06	.744408-05
VACACR	1.91226	.370956	-1.99969	.240051	.744408-05	.205511-02
C	-194818.	-16068.2	31067.8	-39794.8	-.952083-01	-21.2551
	1	2	3	4	5	6

	C
OFFACR	-194818.
DISCBD	-16068.2
DUACRE	31067.8
HWYINT	-39794.8
EMP60	-.952083-01
VACACR	-21.2551
C	534601.
	7

LINE 5.
OLSQ

EQUATION 3.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: OFFICE

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
OFFACR	844.615	186.772	4.52218
DELEMP	601.451	217.530	2.76491
DISCBD	-14.0890	9.76455	-1.44287
DUACRE	-400.102	135.701	-2.94841
HWYINT	85.8478	45.7189	1.87773
C	355.212	225.771	1.57333

R-SQUARED = .8061

LOG OF LIKELIHOOD FUNCTION = -131.346

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.8054

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 592677.

STANDARD ERROR OF THE REGRESSION = 205.752

SUM OF RESIDUALS = .295639-04

MEAN VALUE OF DEPENDENT VARIABLE = 305.900

F-STATISTIC(5., 14.) = 11.6440

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	OFFACR	DELEMP	DISCBD	DUACRE	HWYINT	C
OFFACR	34883.7	-6697.79	1144.73	-3418.58	3951.46	-29102.2
DELEMP	-6697.79	47319.3	-736.557	-3203.73	-574.215	7101.15
DISCBD	1144.73	-736.557	95.3465	-81.2103	226.107	-2070.62
DUACRE	-3418.58	-3203.73	-81.2103	18414.8	-3605.95	941.616
HWYINT	3951.46	-574.215	226.107	-3605.95	2090.22	-5980.48
C	-29102.2	7101.15	-2070.62	941.616	-5980.48	50972.5
	1	2	3	4	5	6

EQUATION 4.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: MANF

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
MANACR	1050.74	597.153	1.75958
C	761.385	334.760	2.27442

R-SQUARED = .1468

LOG OF LIKELIHOOD FUNCTION = -172.521

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9856

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .363972+08

STANDARD ERROR OF THE REGRESSION = 1421.99

SUM OF RESIDUALS = .213623-03

MEAN VALUE OF DEPENDENT VARIABLE = 945.600

F-STATISTIC(1., 18.) = 3.09611

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	MANACR	C
MANACR	356592.	-62517.7
C	-62517.7	112064.
	1	2

EQUATION 5.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HWLMNX

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DISCBD	-2.78590	.679119	-4.10223
DELP2	40.4556	12.3415	3.27801
AUTO2	-135.053	63.4479	-2.12856
MINC	46.5689	19.3215	2.41020
MPR68	.595194-02	.349792-02	1.70157
C	78.7947	48.0493	1.63987

R-SQUARED = .6883

LOG OF LIKELIHOOD FUNCTION = -81.3251

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.5076

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 3985.28

STANDARD ERROR OF THE REGRESSION = 16.872

SUM OF RESIDUALS = .941753-05

MEAN VALUE OF DEPENDENT VARIABLE = 22.935

F-STATISTIC(5., 14.) = 6.18215

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DISCBD	DELP2	AUTO2	MINC	MPR68	C
DISCBD	.461202	-1.22643	19.7129	2.65591	-.390880-04	-22.3840
DELP2	-1.22643	152.313	-119.401	102.544	.257138-01	-129.792
AUTO2	19.7129	-119.401	4025.64	-304.294	-.373194-01	-2293.13
MINC	2.65591	102.544	-304.294	373.322	.335064-01	-362.150
MPR68	-.390880-04	.257138-01	-.373194-01	.335064-01	.122354-04	-.494805-01
C	-22.3840	-129.792	-2293.13	-362.150	-.494805-01	2308.74
	1	2	3	4	5	6

EQUATION 6.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: WHOLE

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
HWYINT	97.1018	23.7292	4.09209
MPR70	-.735730-01	.171831-01	-4.28172
DUACRE	-268.809	77.6841	-3.46028
DISCBD	-11.4364	4.24861	-2.69180
OFFVAC	14.9875	7.43460	2.01591
C	487.849	105.358	4.63039

R-SQUARED = .7852

LOG OF LIKELIHOOD FUNCTION = -120.466

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.2186

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 199668.

STANDARD ERROR OF THE REGRESSION = 119.424

SUM OF RESIDUALS = .448227-04

MEAN VALUE OF DEPENDENT VARIABLE = 150.500

F-STATISTIC(5., 14.) = 10.2338

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	HWYINT	MPR70	DUACRE	DISCBD	OFFVAC	C
HWYINT	563.073	.109960-01	-1093.84	34.9622	-20.6242	-849.661
MPR70	.109960-01	.295258-03	.777411-01	.988541-02	-.822210-01	-.651632
DUACRE	-1093.84	.777411-01	6034.81	-4.15917	10.7679	-921.639
DISCBD	34.9622	.988541-02	-4.15917	18.0507	-5.34734	-379.993
OFFVAC	-20.6242	-.822210-01	10.7679	-5.34734	55.2732	32.4194
C	-849.661	-.651632	-921.639	-379.993	32.4194	11100.3
	1	2	3	4	5	6

EQUATION 7.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HOTEL

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
ZRES	-.968159	.251362	-3.85165
AUTO	229.693	52.8012	4.35014
INCMPL	-150.165	52.1284	-2.88067
C	81.7404	21.5351	3.79568

R-SQUARED = .6969

LOG OF LIKELIHOOD FUNCTION = -98.7268

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9559

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 22709.5

STANDARD ERROR OF THE REGRESSION = 37.6742

SUM OF RESIDUALS = .319481-04

MEAN VALUE OF DEPENDENT VARIABLE = 69.8000

F-STATISTIC(3., 16.) = 12.2624

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	ZRES	AUTO	INCMPL	C
ZRES	.631830-01	.945672	-2.16171	-4.08181
AUTO	.945672	2787.97	-1817.89	-650.777
INCMPL	-2.16171	-1817.89	2717.37	444.536
C	-4.08181	-650.777	444.536	463.760
	1	2	3	4

1. RESIDENTIAL MODEL

EQUATION 8.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HOSPTL

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
OFFACR	190.692	64.5350	2.95485
MPR70	.196279-01	.102566-01	1.91369
C	-23.9110	42.0090	-.569186

R-SQUARED = .3761

LOG OF LIKELIHOOD FUNCTION = -116.930

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.4952

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 140198.

STANDARD ERROR OF THE REGRESSION = 90.8125

SUM OF RESIDUALS = .107586-04

MEAN VALUE OF DEPENDENT VARIABLE = 68.4500

F-STATISTIC(2., 17.) = 5.12333

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	OFFACR	MPR70	C
OFFACR	4164.77	.161220	-1152.95
MPR70	.161220	.105197-03	-.364389
C	-1152.95	-.364389	1764.76
	1	2	3

EQUATION 9.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: CULTUR

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
UNIV	60.2198	16.1777	3.72239
VACACR	.174577-02	.121082-02	1.44181
C	2.54233	8.39803	.302730

R-SQUARED = .4939

LOG OF LIKELIHOOD FUNCTION = -81.8819

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.6911

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 4213.50

STANDARD ERROR OF THE REGRESSION = 15.7433

SUM OF RESIDUALS = .160933-05

MEAN VALUE OF DEPENDENT VARIABLE = 16.5500

F-STATISTIC(2., 17.) = 8.29414

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	UNIV	VACACR	C
UNIV	261.719	-.109717-02	-6.17482
VACACR	-.109717-02	.146608-05	-.918005-02
C	-6.17482	-.918005-02	70.5270
	1	2	3

EQUATION 10.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: CHURCH

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
MINC	201.827	88.6159	2.27755
DISCBD	-4.42480	3.25748	-1.35835
C	-14.6922	128.951	-.113936

R-SQUARED = .4084

LOG OF LIKELIHOOD FUNCTION = -117.272

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.0615

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 145089.

STANDARD ERROR OF THE REGRESSION = 92.3832

SUM OF RESIDUALS = .438690-04

MEAN VALUE OF DEPENDENT VARIABLE = 100.600

F-STATISTIC(2., 17.) = 5.86664

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	MINC	DISCBD	C
MINC	7852.78	121.823	-10108.3
DISCBD	121.823	10.6112	-323.609
C	-10108.3	-323.609	16628.4
	1	2	3

EQUATION 11.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: EDUC

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
VACACR	.407932-01	.304691-01	1.33884
SEWER	2.46382	1.78201	1.38261
DISCBD	-25.4996	11.3157	-2.25347
MPKIDS	184.094	113.419	1.62313
C	243.617	339.818	.716904

R-SQUARED = .6481

LOG OF LIKELIHOOD FUNCTION = -138.227

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9806

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .117939+07

STANDARD ERROR OF THE REGRESSION = 280.404

SUM OF RESIDUALS = .116348-03

MEAN VALUE OF DEPENDENT VARIABLE = 482.150

F-STATISTIC(4., 15.) = 6.90636

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	VACACR	SEWER	DISCBD	MPKIDS	C
VACACR	.926364-03	.161409-01	.201772	-2.12438	-6.95264
SEWER	.161409-01	3.17555	6.45839	-63.9299	-302.892
DISCBD	.201772	6.45839	128.045	-569.896	-3108.09
MPKIDS	-2.12438	-63.9299	-569.896	12863.9	5585.52
C	-6.95264	-302.892	-3108.09	5585.52	115476.
	1	2	3	4	5

1. RESIDENTIAL MODEL

EQUATION 12.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: REC

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
MPACRE	.102870	.277401-01	3.70835
C	-33.5125	92.8600	-.360893

R-SQUARED = .4331

LOG OF LIKELIHOOD FUNCTION = -142.276

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.5283

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .176822+07

STANDARD ERROR OF THE REGRESSION = 313.424

SUM OF RESIDUALS = .762940-05

MEAN VALUE OF DEPENDENT VARIABLE = 192.400

F-STATISTIC(1., 18.) = 13.7518

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	MPACRE	C
MPACRE	.769512-03	-1.68993
C	-1.68993	8622.98
	1	2

2. INDUSTRIAL/OFFICE MODEL

EQUATION 1.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: RES

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DUACRE	3555.22	1172.41	3.03240
VACACR	1.95250	.416064	4.69280
OFFVAC	542.203	128.944	4.20494
VACHSG	-128659.	35403.7	-3.63407
DISCBD	-281.018	125.513	-2.23896
C	-7446.75	3587.67	-2.07565

R-SQUARED = .8151

LOG OF LIKELIHOOD FUNCTION = -183.876

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.4802

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .113289+09

STANDARD ERROR OF THE REGRESSION = 2844.66

SUM OF RESIDUALS = .241852-02

MEAN VALUE OF DEPENDENT VARIABLE = 8435.00

F-STATISTIC(5., 14.) = 12.3472

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DUACRE	VACACR	OFFVAC	VACHSG	DISCBD	C
DUACRE	.137455+07	-125.077	6511.41	.799428+07	88258.1	-.128288+07
VACACR	-125.077	.173109	9.25953	-6314.56	-18.1818	-1024.03
OFFVAC	6511.41	9.25953	16626.6	-.139222+07	-2429.56	-137716.
VACHSG	.799428+07	-6314.56	-.139222+07	.125342+10	.171521+07	-.755565+07
DISCBD	88258.1	-18.1818	-2429.56	.171521+07	15753.4	-124939.
C	-.128288+07	-1024.03	-137716.	-.755565+07	-124939.	.128714+08
	1	2	3	4	5	6

2. INDUSTRIAL/OFFICE MODEL

EQUATION 2.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: COMM

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DUACRE	675.453	158.607	4.25866
ZCOMM	129.980	26.0961	4.98083
OFFACR	-1651.08	460.372	-3.58641
MPE70	.830785-01	.411113-01	2.02082
C	-517.259	335.258	-1.54287

R-SQUARED = .7753

LOG OF LIKELIHOOD FUNCTION = -148.981

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.8428

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .345713+07

STANDARD ERROR OF THE REGRESSION = 480.078

SUM OF RESIDUALS = .289440-03

MEAN VALUE OF DEPENDENT VARIABLE = 1022.15

F-STATISTIC(4., 15.) = 12.9412

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DUACRE	ZCOMM	OFFACR	MPE70	C
DUACRE	25156.1	-651.261	2415.89	.467425	-18911.9
ZCOMM	-651.261	681.008	-7918.86	.136378	-3057.60
OFFACR	2415.89	-7918.86	211942.	-3.02865	25129.3
MPE70	.467425	.136378	-3.02865	.169014-02	-11.3469
C	-18911.9	-3057.60	25129.3	-11.3469	112398.
	1	2	3	4	5

EQUATION 3.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: OFFICE

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
RRMI	13.8850	5.37706	2.58227
ZOFF	67.4672	19.5253	3.45537
MPE70	-.316890-01	.116619-01	-2.71731
MINC	489.752	200.045	2.44821
MANACR	223.667	119.521	1.87137
C	-349.544	220.143	-1.58781

R-SQUARED = .6593

LOG OF LIKELIHOOD FUNCTION = -121.445

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.4314

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 220205.

STANDARD ERROR OF THE REGRESSION = 125.415

SUM OF RESIDUALS = .286102-05

MEAN VALUE OF DEPENDENT VARIABLE = 179.550

F-STATISTIC(5., 14.) = 5.41733

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	RRMI	ZOFF	MPE70	MINC	MANACR	C
RRMI	28.9127	-13.1999	.349213-02	69.1007	-110.480	-282.692
ZOFF	-13.1999	381.238	-.891792-01	480.441	455.275	-313.285
MPE70	.349213-02	-.891792-01	.136000-03	-.379355	-.307666	-.338817
MINC	69.1007	480.441	-.379355	40017.8	8072.31	-40544.1
MANACR	-110.480	455.275	-.307666	8072.31	14285.2	-9696.91
C	-282.692	-313.285	-.338817	-40544.1	-9696.91	48462.9
	1	2	3	4	5	6

2. INDUSTRIAL/OFFICE MODEL

INFONET TSP

EQUATION 4.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: MANF

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DELEMP	10113.6	3346.20	3.02240
MINCC	-2623.49	1307.80	-2.00603
VACACR	.252297	.179887	1.40253
C	1121.07	1737.87	.645082

R-SQUARED = .4741

LOG OF LIKELIHOOD FUNCTION = -169.447

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.3809

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .267641+08

STANDARD ERROR OF THE REGRESSION = 1293.35

SUM OF RESIDUALS = .327587-03

MEAN VALUE OF DEPENDENT VARIABLE = 1545.70

F-STATISTIC(3., 16.) = 4.80765

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DELEMP	MINCC	VACACR	C
DELEMP	.111971+08	-998975.	-144.174	.110844+07
MINCC	-998975.	.171034+07	-56.8196	-.124458+07
VACACR	-144.174	-56.8196	.323593-01	-200.589
C	.110844+07	-.124458+07	-200.589	.302018+07
	1	2	3	4

EQUATION 5.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HWLMNX

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
VACACR	.574184-02	.191887-02	2.99230
HWYINT	-5.60785	1.71961	-3.26111
DUACRE	14.2396	4.93252	2.88689
OFFVAC	.915400	.660151	1.38665
C	-22.9269	18.2013	-1.25963

R-SQUARED = .6519

LOG OF LIKELIHOOD FUNCTION = -79.4970

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9565

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 3319.44

STANDARD ERROR OF THE REGRESSION = 14.8760

SUM OF RESIDUALS = .177026-04

MEAN VALUE OF DEPENDENT VARIABLE = 31.9950

F-STATISTIC(4., 15.) = 7.02229

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	VACACR	HWYINT	DUACRE	OFFVAC	C
VACACR	.366207-05	.104191-03	-.849081-03	.418295-04	-.314397-01
HWYINT	.104191-03	2.95708	-.986078	-.266171	-4.65433
DUACRE	-.849081-03	-.986078	24.3298	.592369	-14.1386
OFFVAC	.418295-04	-.266171	.592369	.435800	-3.69930
C	-.314397-01	-4.65433	-14.1386	-3.69930	331.288
	1	2	3	4	5

LINE 8.
OLSQ

2. INDUSTRIAL/OFFICE MODEL

EQUATION 6.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: WHOLE

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
WWEA	7467.78	5003.96	1.49237
ZIND	90.8420	27.9858	3.24600
SEWER	11.4350	5.57329	2.05175
DUACRE	725.642	384.803	1.88575
C	-1650.77	448.080	-3.68410

R-SQUARED = .7744

LOG OF LIKELIHOOD FUNCTION = -160.047

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9309

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .104548+08

STANDARD ERROR OF THE REGRESSION = 834.857

SUM OF RESIDUALS = .877380-04

MEAN VALUE OF DEPENDENT VARIABLE = 882.850

F-STATISTIC(4., 15.) = 12.8709

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	WWEA	ZIND	SEWER	DUACRE	C
WWEA	.250396+08	-51180.4	470.985	-.134099+07	457564.
ZIND	-51180.4	783.208	-25.4210	2228.98	-7004.19
SEWER	470.985	-25.4210	31.0616	-301.431	-1109.66
DUACRE	-.134099+07	2228.98	-301.431	148073.	-63565.9
C	457564.	-7004.19	-1109.66	-63565.9	200776.
	1	2	3	4	5

2. INDUSTRIAL/OFFICE MODEL

EQUATION 7.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HOTEL

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
DISCBD	-11.5140	3.76318	-3.05964
DELEMP	1182.05	385.723	3.06451
OFFACR	-249.174	109.656	-2.27233
C	145.184	46.6174	3.11437

R-SQUARED = .4595

LOG OF LIKELIHOOD FUNCTION = -119.487

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.4542

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 181054.

STANDARD ERROR OF THE REGRESSION = 106.376

SUM OF RESIDUALS = .371933-04

MEAN VALUE OF DEPENDENT VARIABLE = 102.200

F-STATISTIC(3., 16.) = 4.53418

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	DISCBD	DELEMP	OFFACR	C
DISCBD	14.1615	-555.762	99.6724	-108.405
DELEMP	-555.762	148782.	-30440.4	-4130.45
OFFACR	99.6724	-30440.4	12024.3	-148.614
C	-108.405	-4130.45	-148.614	2173.18
	1	2	3	4

EQUATION 6.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: HOSPTL

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
NONHSE	477.573	228.398	2.09097
MANACR	442.980	159.240	2.78184
OFFACR	-283.253	127.150	-2.22770
C	-20.5055	53.0288	-.386687

R-SQUARED = .5140

LOG OF LIKELIHOOD FUNCTION = -127.332

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.9446

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 396759.

STANDARD ERROR OF THE REGRESSION = 157.472

SUM OF RESIDUALS = .367165-04

MEAN VALUE OF DEPENDENT VARIABLE = 91.4500

F-STATISTIC(3., 16.) = 5.64018

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	NONHSE	MANACR	OFFACR	C
NONHSE	52165.8	-10145.5	-2227.39	-1009.08
MANACR	-10145.5	25357.4	-8491.16	-4787.35
OFFACR	-2227.39	-8491.16	16167.2	-547.678
C	-1009.08	-4787.35	-547.678	2812.05
	1	2	3	4

EQUATION 9.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: CULTUR

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
ENERGY	-34.6241	16.2547	-2.13010
EMP60	.439357-04	.206780-04	2.12475
MPACRE	.410940-01	.209451-01	1.96198
PVTSCH	12.5543	8.56493	1.46578
C	23.5859	18.5780	1.26956

R-SQUARED = .4312

LOG OF LIKELIHOOD FUNCTION = -82.7249

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.4391

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 4584.09

STANDARD ERROR OF THE REGRESSION = 17.4816

SUM OF RESIDUALS = .435114-05

MEAN VALUE OF DEPENDENT VARIABLE = 12.9000

F-STATISTIC(4., 15.) = 2.84329

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	ENERGY	EMP60	MPACRE	PVTSCH	C
ENERGY	264.215	-.105855-03	.366510-01	13.1479	-257.839
EMP60	-.105855-03	.427579-09	.823688-07	.231915-05	.215793-06
MPACRE	.366510-01	.823688-07	.438699-03	.702592-01	-.186684
PVTSCH	13.1479	.231915-05	.702592-01	73.3581	-62.9573
C	-257.839	.215793-06	-.186684	-62.9573	345.142
	1	2	3	4	5

EQUATION 10.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: CHURCH

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
RRMI	8.65488	3.04583	2.84155
VACACR	.313526-01	.113178-01	2.77021
SEWER	-1.06916	.574616	-1.86065
MPET2	-.145485-01	.805126-02	-1.80698
C	-147.539	90.1540	-1.63652

R-SQUARED = .4764

LOG OF LIKELIHOOD FUNCTION = -110.120

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 1.8564

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 70959.6

STANDARD ERROR OF THE REGRESSION = 68.7797

SUM OF RESIDUALS = .176430-04

MEAN VALUE OF DEPENDENT VARIABLE = 94.4000

F-STATISTIC(4., 15.) = 3.41175

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	RRMI	VACACR	SEWER	MPET2	C
RRMI	9.27706	.970243-02	-.566348	-.205648-02	-123.864
VACACR	.970243-02	.128092-03	-.396683-02	-.229718-04	-.904203
SEWER	-.566348	-.396683-02	.330184	.107381-02	18.3747
MPET2	-.205648-02	-.229718-04	.107381-02	.648229-04	-.295834-01
C	-123.864	-.904203	18.3747	-.295834-01	8127.74
	1	2	3	4	5

2. INDUSTRIAL/OFFICE MODEL

EQUATION 11.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: EDUC

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
MPET2	.110577	.441740-01	2.50323
VACACR	.993291-01	.505882-01	1.96348
RRMI	25.1254	16.2560	1.54561
C	-730.439	475.462	-1.53627

R-SQUARED = .4577

LOG OF LIKELIHOOD FUNCTION = -145.365

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.4306

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = .240822+07

STANDARD ERROR OF THE REGRESSION = 387.961

SUM OF RESIDUALS = .408173-03

MEAN VALUE OF DEPENDENT VARIABLE = 646.050

F-STATISTIC(3., 16.) = 4.50080

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	MPET2	VACACR	RRMI	C
MPET2	.195134-02	-.320427-03	-.682849-02	-2.84254
VACACR	-.320427-03	.255917-02	.922152-01	-21.7451
RRMI	-.682849-02	.922152-01	264.258	-2938.16
C	-2.84254	-21.7451	-2938.16	226064.
	1	2	3	4

2. INDUSTRIAL/OFFICE MODEL

EQUATION 12.
****

ORDINARY LEAST SQUARES

DEPENDENT VARIABLE: REC

RIGHT-HAND VARIABLE	ESTIMATED COEFFICIENT	STANDARD ERROR	T-STATISTIC
OFFVAC	17.5654	5.95976	2.94734
DELEMP	1441.24	508.061	2.83675
MINCC	387.011	134.366	2.88029
AUTO	-615.075	231.318	-2.65900
DISCBD	14.7740	6.05910	2.43831
MANACR	188.228	132.862	1.41672
C	-603.804	155.590	-3.88074

R-SQUARED = .7504

LOG OF LIKELIHOOD FUNCTION = -120.354

DURBIN-WATSON STATISTIC (ADJ. FOR 0. GAPS) = 2.1696

NUMBER OF OBSERVATIONS = 20.

SUM OF SQUARED RESIDUALS = 197451.

STANDARD ERROR OF THE REGRESSION = 123.242

SUM OF RESIDUALS = .431538-04

MEAN VALUE OF DEPENDENT VARIABLE = 140.250

F-STATISTIC(6., 13.) = 6.51368

ESTIMATE OF VARIANCE-COVARIANCE MATRIX OF ESTIMATED COEFFICIENTS

	OFFVAC	DELEMP	MINCC	AUTO	DISCBD	MANACR
OFFVAC	35.5187	545.693	-63.8581	150.407	-12.3112	-270.879
DELEMP	545.693	258126.	-2693.07	-84271.5	509.069	-22491.1
MINCC	-63.8581	-2693.07	18054.1	-6314.30	.765480	4227.70
AUTO	150.407	-84271.5	-6314.30	53508.2	-764.195	3770.23
DISCBD	-12.3112	509.069	.765480	-764.195	36.7126	249.132
MANACR	-270.879	-22491.1	4227.70	3770.23	249.132	17652.3
C	-109.363	-3914.62	-18029.1	6258.15	-195.276	-8744.56
	1	2	3	4	5	6

	C
OFFVAC	-109.363
DELEMP	-3914.62
MINCC	-18029.1
AUTO	6258.15
DISCBD	-195.276
MANACR	-8744.56
C	24208.3
	7

```
LINE 15.
        SMPL

SMPL =      1.    4.    6.    9.   13.   13.   18.   18.
LINE 16.
        OLSQ
```

APPENDIX B

GRAPHS OF ACTUAL VERSUS PREDICTED LAND USE
FOR THE CROSS-VALIDATION ANALYSIS

1. RESIDENTIAL MODEL

RES EQUATION

```
                                  PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(O)

 ID    ACTUAL      FITTED                                                              RESIDUAL
                                                                                                    0.0
  14   .1008+05    -1503.   +                 *                                         .116+05   .     .     .  0
                          -------------------------------------------------
  21   877.0       .1073+05  *                  +                                      -.985+04 0.     .     .
  22   958.0       1903.     * +                                                       -945.     .    0.     .
  23   8234.       9439.                    * +                                        -.121+04  .    0.     .
                          -------------------------------------------------
  27   3662.       .1079+05       *             +                                      -.713+04 .0     .     .
  29   1122.       5139.     *       +                                                 -.402+04  .  0  .     .
  30   .2338+05    4540.           +                                                 *  .188+05  .     .     .      0
  35   3348.       3618.          +                                                    -270.     .     0     .
                          -------------------------------------------------
  37      0.       1804.    *  +                                                       -.180+04  .    0.     .
  40   5990.       1906.       +     *                                                  .408+04  .     .   0 .
                 LINE 11.
                       STOP
```


COMM EQUATION

```
                                  PLOT OF ACTUAL(*) AND FITTED(+) VALUES                    PLOT OF RESIDUALS(O)

 ID    ACTUAL      FITTED                                                              RESIDUAL
                                                                                                   0.0
  14   945.0       698.3        + *                                                     247.     .    . 0    .
                          -------------------------------------------------
  21   533.0       581.2      +                                                        -48.2     .     0     .
  22   322.0       530.1   *  +                                                        -208.     .   0 .     .
  23   715.0       1094.        *   +                                                  -379.     .  0  .     .
                          -------------------------------------------------
  27   388.0       881.6     *    +                                                    -494.     . 0   .     .
  29   1438.       1505.               +                                               -67.0     .     0     .
  30   4355.       2254.                     +                                       *  .210+04  .     .     .      0
  35   1489.       1375.              +*                                                114.     .    .0     .
                          -------------------------------------------------
  37   828.0       1344.       *    +                                                  -516.     . 0   .     .
  40   975.0       1464.         *    +                                                -489.     . 0   .     .
                 LINE 56.
                       ACTFIT
```

OFFICE EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	40.00	820.0	-780.
21	8.000	278.0	-270.
22	13.00	143.4	-130.
23	625.0	321.9	303.
27	510.0	261.1	249.
29	742.0	479.0	263.
30	125.0	632.4	-507.
35	248.0	56.91	191.
37	200.0	366.4	-166.
40	670.0	618.0	52.0

LINE 57.
ACTFIT

MANF EQUATION

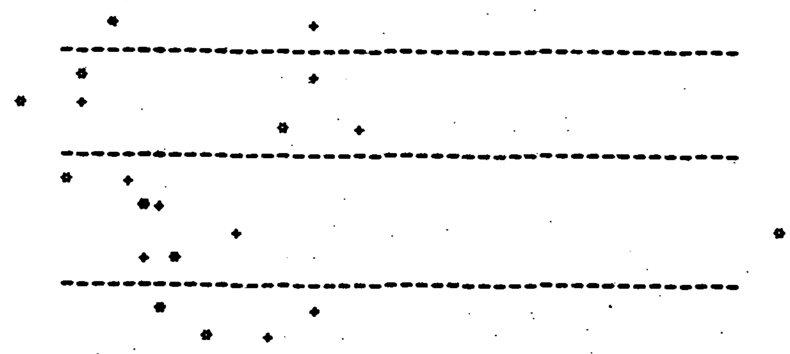
PLOT OF ACTUAL(*) AND FITTED(+) VALUES PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	875.0	407.9	467.
21	573.0	407.9	165.
22	22.00	512.4	-490.
23	334.0	432.7	-98.7
27	114.0	397.9	-284.
29	60.00	397.9	-338.
30	117.0	743.0	-626.
35	5427.	769.2	.466+04
37	703.0	460.0	243.
40	4205.	435.7	.377+04

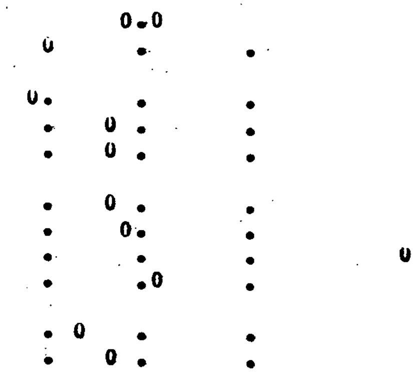
LINE 58.
ACTFIT

HWLMNX EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES



PLOT OF RESIDUALS(0)

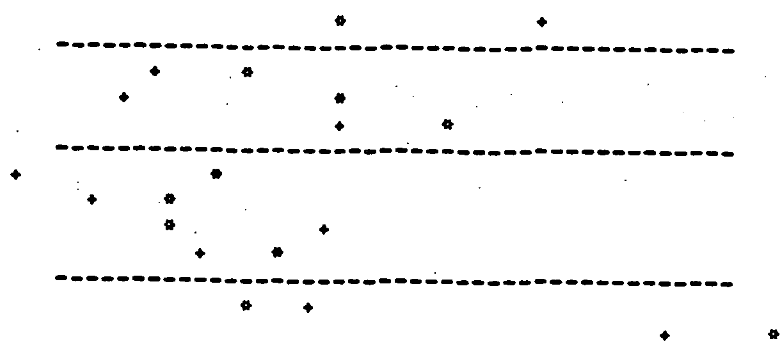


ID	ACTUAL	FITTED	RESIDUAL
14	12.00	39.73	-27.7
21	8.000	40.17	-32.2
22	0.	8.743	-8.74
23	35.40	47.29	-11.9
27	6.800	15.23	-8.43
29	16.40	19.87	-3.47
30	103.2	28.74	74.5
35	21.20	17.36	3.84
37	20.00	39.44	-19.4
40	26.30	34.40	-8.10

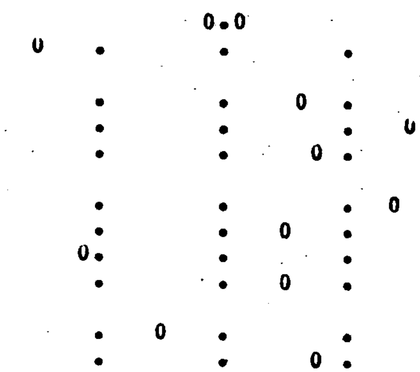
LINE 59.
ACTFIT

WHOLE EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES



PLOT OF RESIDUALS(0)



ID	ACTUAL	FITTED	RESIDUAL
14	242.0	554.6	-313.
21	111.0	-32.20	143.
22	256.0	-77.35	333.
23	423.0	244.2	179.
27	61.00	-242.1	303.
29	0.	-114.4	114.
30	0.	226.9	-227.
35	160.0	44.86	115.
37	113.0	202.8	-89.8
40	905.0	742.3	163.

LINE 60.
ACTFIT

HOTEL EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	77.00	70.07	6.93
21	160.0	83.50	76.5
22	4.000	12.67	-8.67
23	0.	43.05	-43.1
27	45.00	123.1	-78.1
29	195.0	88.13	107.
30	117.0	62.25	54.8
35	121.0	68.50	52.5
37	135.0	59.52	75.5
40	168.0	84.88	83.1

0.0

LINE 61.
ACTFIT

HOSPTL EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	40.00	33.86	6.14
21	87.00	-8.691	95.7
22	0.	16.27	-16.3
23	0.	-44.74	44.7
27	0.	19.07	-19.1
29	203.0	95.93	107.
30	359.0	55.24	304.
35	155.0	13.84	141.
37	30.00	106.0	-76.0
40	0.	-42.29	42.3

0.0

LINE 62.
ACTFIT

CULTUR EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	0.	11.99	-12.0
21	55.00	12.13	42.9
22	0.	10.94	-10.9
23	4.000	12.51	-8.51
27	21.00	12.87	8.13
29	0.	7.403	-7.40
30	47.00	13.48	33.5
35	0.	11.70	-11.7
37	75.00	12.13	62.9
40	15.00	13.92	1.08

LINE 63.
ACTFIT

CHURCH EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	45.00	73.64	-28.6
21	3.000	37.00	-34.0
22	63.00	73.03	-10.0
23	280.0	81.12	199.
27	35.00	41.87	-6.87
29	23.00	63.48	-40.5
30	504.0	121.1	383.
35	152.0	75.01	77.0
37	135.0	94.15	40.9
40	108.0	118.4	-10.4

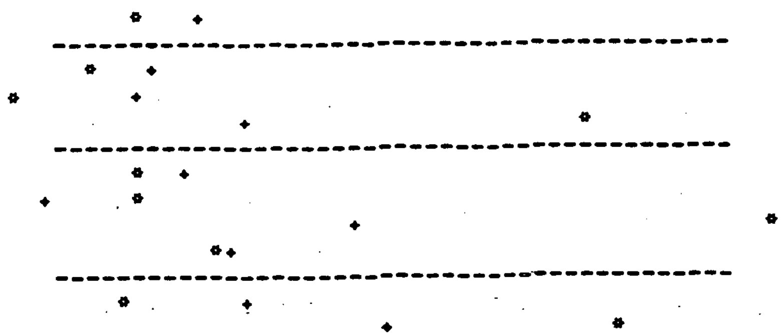
LINE 64.
ACTFIT

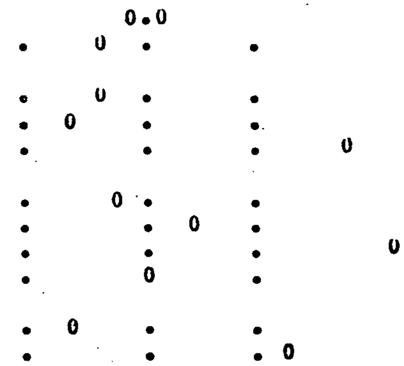
EDUC EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	336.0	454.3	-118.
21	256.0	381.5	-125.
22	121.0	339.9	-219.
23	1176.	553.9	622.
27	350.0	423.4	-73.4
29	359.0	182.2	177.
30	1504.	732.6	771.
35	496.0	504.4	-8.42
37	330.0	551.7	-222.
40	1208.	785.8	422.





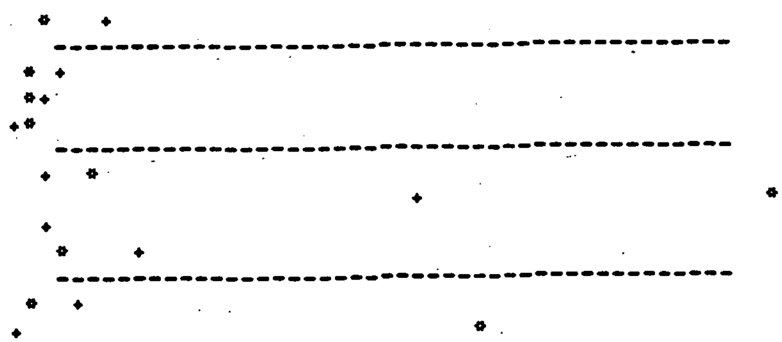
LINE 65.
ACTFIT

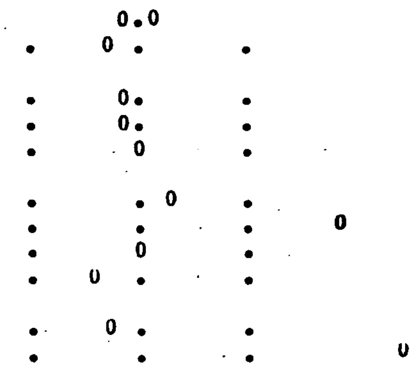
REC EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
14	20.00	122.9	-103.
21	0.	54.55	-54.5
22	0.	21.08	-21.1
23	0.	-17.74	17.7
27	112.0	29.30	82.7
29	1250.	658.1	592.
30	31.00	35.52	-4.52
35	66.00	182.5	-117.
37	0.	90.86	-90.9
40	746.0	-21.20	767.



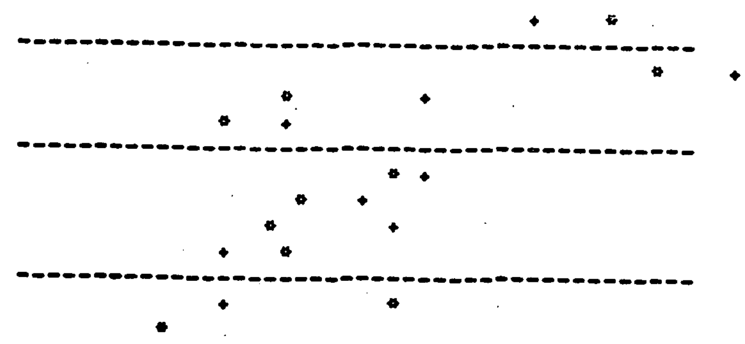


LINE 66.
STOP

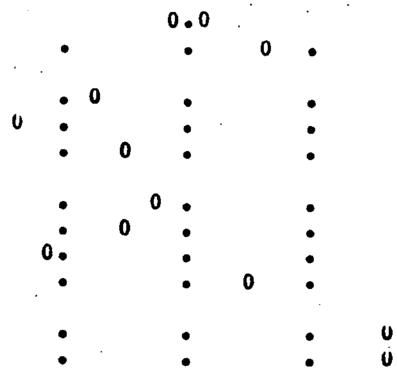
2. INDUSTRIAL/OFFICE MODEL

RES EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES



PLOT OF RESIDUALS(0)

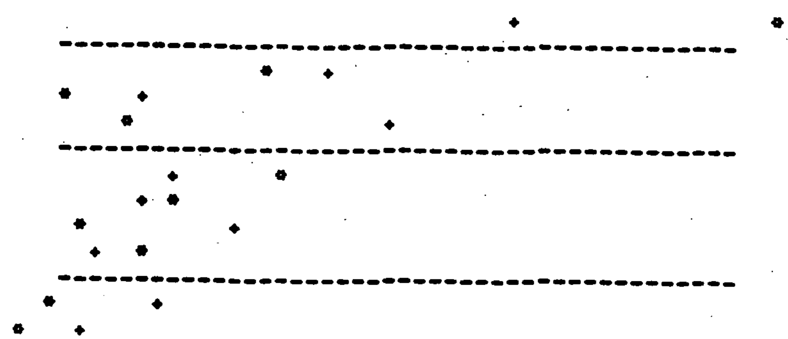


ID	ACTUAL	FITTED	RESIDUAL
8	.1965+05	.1667+05	.299+04
17	.2154+05	.2486+05	-.332+04
18	5674.	.1215+05	-.647+04
24	3608.	5723.	-.212+04
28	.1054+05	.1185+05	-.131+04
31	6697.	9218.	-.252+04
32	5452.	.1061+05	-.516+04
33	5938.	3604.	.233+04
38	.1084+05	3031.	.781+04
39	830.0	-7083.	.791+04

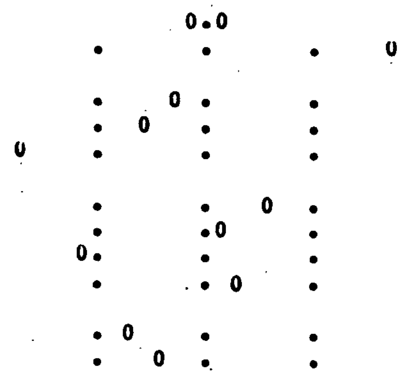
LINE 55.
ACTFIT

COMM EQUATION

Plot of Actual (*) AND FITTED(+) VALUES



PLOT OF RESIDUALS(0)



ID	ACTUAL	FITTED	RESIDUAL
8	4300.	2873.	.143+04
17	1497.	1788.	-291.
18	360.0	816.0	-456.
24	731.0	2155.	-.142+04
28	1519.	995.0	524.
31	922.0	829.5	92.5
32	408.0	1327.	-919.
33	812.0	546.5	265.
38	291.0	890.6	-600.
39	107.0	481.4	-374.

LINE 56.
ACTFIT

OFFICE EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	573.0	-236.1	809.
17	86.00	803.8	-718.
18	0.	115.5	-116.
24	80.00	346.8	-267.
28	188.0	181.1	6.95
31	78.00	340.7	-263.
32	192.0	256.8	-64.8
33	135.0	105.8	29.2
38	322.0	-196.7	519.
39	6.000	108.4	-102.

LINE 57.
ACTFIT

MANF EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	6730.	2009.	.472+04
17	144.0	1999.	-.185+04
18	403.0	1924.	-.152+04
24	3359.	965.4	.239+04
28	1091.	1522.	-431.
31	500.0	1746.	-.125+04
32	352.0	1838.	-.149+04
33	3484.	821.2	.266+04
38	142.0	-215.2	357.
39	0.	-1194.	.119+04

LINE 58.
ACTFIT

HWLMNX EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	56.40	50.85	5.55
17	81.20	99.89	-18.7
18	8.000	35.24	-27.2
24	12.80	21.44	-8.64
28	23.60	57.14	-33.5
31	23.40	29.02	-5.62
32	32.50	41.17	-8.67
33	47.20	8.524	38.7
38	11.20	4.075	7.13
39	12.00	-9.689	21.7

LINE 59.
ACTFIT

WHOLE EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	2605.	5780.	-.317+04
17	4046.	4681.	-635.
18	29.00	-1180.	.121+04
24	668.0	957.8	-290.
28	599.0	738.1	-139.
31	0.	-656.4	656.
32	152.0	2042.	-.189+04
33	189.0	40.12	149.
38	232.0	1202.	-970.
39	7.000	405.8	-399.

LINE 60.
ACTFIT

HOTEL EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	583.0	207.3	376.
17	58.00	-103.1	161.
18	29.00	50.24	-21.2
24	147.0	-117.3	264.
28	41.00	80.89	-39.9
31	285.0	105.7	179.
32	0.	114.7	-115.
33	20.00	82.45	-62.4
38	35.00	8.607	26.4
39	11.00	69.30	-58.3

LINE 61.
ACTFIT

HOSPTL EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	585.0	409.2	176.
17	0.	925.6	-926.
18	72.00	273.7	-202.
24	3.000	307.9	-305.
28	0.	328.3	-328.
31	125.0	137.3	-12.3
32	0.	-81.38	81.4
33	0.	-87.57	87.6
38	63.00	210.2	-147.
39	23.00	-92.35	115.

LINE 62.
ACTFIT

CULTUR EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	45.00	1.179	43.8
17	0.	-3.813	3.81
18	0.	-.9939	.994
24	11.00	4.287	6.71
28	44.00	4.998	39.0
31	59.00	15.05	43.9
32	56.00	-24.88	80.9
33	0.	-7.231	7.23
38	0.	7.338	-7.34
39	0.	10.13	-10.1

LINE 63.
ACTFIT

CHURCH EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES — PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	305.0	209.2	95.8
17	75.00	39.26	35.7
18	58.00	69.14	-11.1
24	77.00	123.3	-46.3
28	138.0	111.7	26.3
31	144.0	81.86	62.1
32	22.00	49.34	-27.3
33	18.00	-45.10	63.1
38	51.00	215.6	-165.
39	25.00	15.02	9.98

LINE 64.
ACTFIT

EDUC EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	1483.	919.3	564.
17	576.0	459.1	117.
18	216.0	469.4	-253.
24	401.0	781.3	-380.
28	736.0	859.8	-124.
31	328.0	487.5	-159.
32	724.0	724.4	-.407
33	353.0	326.2	26.8
38	344.0	337.5	6.46
39	102.0	-387.2	489.

LINE 65.
ACTFIT

REC EQUATION

PLOT OF ACTUAL(*) AND FITTED(+) VALUES

PLOT OF RESIDUALS(0)

ID	ACTUAL	FITTED	RESIDUAL
8	0.	764.8	-765.
17	500.0	1516.	-.102+04
18	325.0	1385.	-.106+04
24	450.0	886.4	-436.
28	65.00	47.42	17.6
31	0.	482.3	-482.
32	56.00	-576.5	632.
33	150.0	-49.42	199.
38	13.00	378.0	-365.
39	3.000	378.8	-376.

LINE 66.
STOP

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
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16. ABSTRACT

Growth Effects of Major Land Use Projects is a research program whose goal is to formulate a methodology to predict air pollutant emissions resulting from the construction and operation of two types of major land use projects, large residential projects and large concentrations of employment (i.e., office parks and industrial parks). Emissions are quantified from the major project, from land use induced by the major project, from secondary activity occurring off-site (ie., generation of electricity by utilities), and from motor vehicle traffic associated with both the major project and its induced land uses.

This volume provides a summary of the first two volumes, viz. the specification and causal analysis of the land use model and the development of the land use based emission factors. It also discusses the development of the predictive equations in the land use model and the development of the traffic model. A set of computation worksheets and step by step instructions for using the GEMLUP model, as well as an example of their use, are provided.

Previous volumes document the development of the land use model and the development of a set of land use based emission factors.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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