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An Econometric Model of Intraurban Location
of Emitters and Receptors of Industrial
Air Pollution

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ARGONNE NATIONAL LABORATORY

ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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Argonne, Illinois 60439

**An Econometric Model of Intraurban Location
of Emitters and Receptors of Industrial
Air Pollution**

by

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ABSTRACT

An econometric model of intraurban location is constructed and estimated. The model treats employment and population as simultaneously determined. Exogenous variables are selected to represent transportation infrastructure investments resulting primarily from federal and state decisions. The exogenous variables account for the relative services provided by highways, commuter railroads, rail rapid transit, waterways, and airports. The employment location equations appear to be considerably more successful than those in previous studies. These equations indicate that waterway availability constrains the locational options of most major industrial air polluters; that highway accessibility is a more influential factor in industrial than services location choices; that rail rapid transit accessibility is more important to services than industrial locations; and that major airports attract light industrial development. The success of the employment location equations reflects the importance of disaggregating intraurban modes of transport and of adding to urban location models the local effects of interurban modes of transport such as water and air.

1. INTRODUCTION

This report examines the determinants of location of industries, businesses, and residences in the Chicago Standard Consolidated Statistical Area. It uses employment as a measure of industrial and business firm size and uses population as a measure of number of residences. The major purpose of the report is to identify the locational constraints acting on major air polluters. It is found that major air polluters can be divided into two categories as far as locational flexibility is concerned. The first category, which accounts for a substantial majority of emissions and employment, consists of industries consuming large quantities of water. These industries are typically involved in the first stage of production, processing substantial quantities of raw materials. Many of these industries ship millions of tons of bulky raw materials via commercial waterways. The two factors of water consumption for processing and use of waterways for shipping are shown to cause the majority of major industrial air polluters to locate adjacent to navigable waterways. The results of this report also indicate that these industries are not positively influenced by intraurban availability of labor. The research conducted to date on the second category, non-water using major air polluters, has not yet explicitly identified locational constraints acting on these remaining air polluters.

A secondary purpose of this report is to identify determinants of location of receptors (businesses and residences) of the emissions resulting from major industrial air polluters. The means of examining these relationships is a simultaneous equations econometric model adapted from previous work by Donald Steinnes and Walter Fisher³³. The model treats employment (business and industrial) as being simultaneously determined with population. There are five equations in the model. A vector of three employment equations is simultaneously estimated with a vector of two population equations by the method of three-stage least squares (3SLS). The employment vector includes (1) major water-using air polluting employment, (2) other manufacturing employment, and (3) nonmanufacturing employment. The population vector includes black and white population. The independent variables in the model are based primarily on the transportation infrastructure of the Chicago-Gary metropolitan area, on the premise that major transportation

infrastructure investments are committed primarily at the federal and state levels. The argument is that, at the large scale, transportation infrastructure is a result of decisions made exogenous to a metropolitan area. Transportation infrastructure considered includes airports, highways, commuter rail, rail rapid transit, and waterways. Model results indicate that all of these modes of transportation play a strong role in determining intra-urban locations of industry, businesses, and residences.

2. CONCEPT AND RATIONALE

The "Environmental Pollutants and the Urban Economy Project" attempts to apply cost-benefit analysis to environmental policy considerations. Most of the project work to date involves air pollution. Costs of air pollution include property damage and human health effects. Causes of air pollution in urban areas are emissions from autos, trucks, industries, businesses and residences. The latter three of these are immobile, while the former two are mobile. The degree of damage suffered by persons and property depends, in part, on the proximity of animate persons and inanimate property receptors to the above mentioned mobile and immobile emitters. It is obvious that the easiest part of the spatial juxtaposition problem is the relationship of inanimate receptors and immobile emitters. The contents of this report are primarily concerned with only this portion of the much broader receptor-emitter proximity problem. Locational characteristics of major industrial air polluters are modeled in conjunction with other industrial, business, and residence locational attributes.

The work presented here is static in nature, while emitter-receptor locational adjustments are an important aspect of the problem. However, other spatial modeling work of the Project is quite substantial and can be used to reasonably infer dynamic adjustments of major industrial emitters. The results of work by Campbell and Santini³ indicate that probable Chicago area growth of major industrial emitters will be within or adjacent to existing clusters of such industry, generally regardless of environmental policies. Further, such growth will tend to be at or beyond the current urban fringe, as defined later in this document. Other employment and population adjustments can conceivably be predicted by using the model presented below in a comparative static format.

A major objective of the Project is to do policy-oriented work. The selection of dependent (endogenous) and independent (exogenous) variables for the model takes this objective into account by selecting private sector variables as dependent and public sector variables as independent. The spatial model is a regional urban model encompassing urbanized areas in the Chicago Standard Consolidated Area (SCA), including both the

Chicago and Gary-Hammond Standard Metropolitan Statistical Areas (SMSAs). Consequently, the public sector variables selected as exogenous are those which may be considered truly regional. Highly localized public services such as schools, fire protection, or police protection are therefore not considered.

In most urban areas, government functions are very fragmented. The Chicago area is no exception. As a result, there are actually very few truly regional functions. The major exception is in the area of transportation infrastructure. Historically, as the examples below demonstrate, the United States government has been heavily involved in the financing and construction of transportation systems. Campbell and Santini³ show that federally financed canals and harbors are major determinants of the locations of Chicago's Loop and the Calumet region's heavy industry. Railroads, supported by federal land grants, were instrumental in the growth of Chicago's satellite cities. Present suburban population densities are clearly related to commuter rail service, originally provided as intercity passenger service connecting Chicago to its satellite cities. Within the city itself, older local railroads have long since been integrated into a rail rapid transit system. The level of rail rapid transit service provided by the Chicago Transit Authority would have been difficult to supply without federal funding of capital equipment. Recently, federal investments in interstate highways have supported further suburban growth in areas not well served by commuter rail. Even air transportation must be included on the list of transportation systems whose location and activity are controlled federally.

Aside from transportation infrastructure investments, another federally supported service influencing the spatial distribution of employment and population is sewage treatment and water supply. The results of prior empiric spatial modeling work^{26,36} indicate that these effects are significant. The modeling results presented in this report indicate that the flows from the extremely large sewage treatment plants in Chicago allow the construction of larger water using industrial plants (power plants) downstream of these plants. These results are pertinent to the current Chicago area debate over the withdrawal and allocation of additional water from Lake Michigan.

One example of a regional concept in public services not mandated federally is the local park system. The forest preserves and parks, while not planned at the metropolitan level, were planned at the county level. Forest preserve lands earlier acquired in rural areas are now surrounded by residences. In suburban Cook County and the City of Chicago, the lakefront and other park lands are largely the result of suggestions in the 1909 plan by Daniel Burnham. These park lands have an important effect today on residential location. The protection of Chicago lakefront for public use is partially responsible for industrial expansion to the south of Calumet Harbor, in Indiana (see Campbell and Santini³). The federal government is not completely absent even from this area of public land use policy. Conflict between industrial expansion and public recreation often manifests itself along waterways or bodies of water. While waterways are valuable to many industries for shipping and water consumption purposes, they are also valuable recreationally for fishing, boating, and purely aesthetic reasons.³⁴

Although transportation infrastructure, water supply/treatment and park lands are, according to results presented here and elsewhere, important determinants of regional population and employment structure, it is not clear that coordinated metropolitan planning of these activities takes place. Still, there is movement in this direction. Several examples may be cited. First, in the Chicago SMSA, recent action by the State of Illinois has created the Regional Transit Authority, responsible for bus, rail transit, and commuter rail service. Additionally, the Authority can affect the cost of automobile travel by levying gasoline and parking taxes. Second, the Federal Government now requires, under Office of Management and Budget Circular No. A-95, state, regional, and metropolitan review of applications for assistance under some 100 federal grant and loan programs. In the Illinois portion of the Chicago SCA, this function is performed by the Northeastern Illinois Planning Commission. Third, there seems to be an increasing amount of inter-agency coordination in the region. This manifested itself in data collection efforts for this study. Northeastern Illinois Planning Commission data was generally compatible with Northwestern Indiana Planning Commission data. The Northwestern Indiana Planning Commission also conducted traffic research compatible with the needs of the Chicago Area Transportation Study. The

collection of compatible data by independent agencies makes meaningful integrated regional studies such as this possible. Hopefully, the careful use of such data in this and other studies can lead to a better comprehension of the presently poorly understood interactive effects of various public policy actions. If so, then more effective interagency coordination may be expected to follow.

3. RELATION TO SELECTED PREVIOUS URBAN MODELS

The model to be presented in this report is conceptually linked to three previous spatial modeling efforts. These are Lowry's "Model of Metropolis,"¹⁸ Peat, Marwich and Mitchell's "Empiric Activity Allocation Model Application to the Washington Region,"²⁶ and Steinnes and Fisher's "An Econometric Model of Intraurban Location."³³ These models are all similar in the sense that they attempt, in part, to determine the locations of residents and employees as a function of the accessibility of one to the other.

3.1 LOWRY'S "MODEL OF METROPOLIS"

The Lowry model is the first of a class of urban simulation models which assert that export (basic) industries of a city are responsible for the existence and size of the city. According to the Lowry model, the location of these industries is not influenced by accessibility to population. His model essentially requires that the modeler use judgment and external information in locating basic industries. The model internally uses an interactive feedback loop. In this loop, basic employment determines first round number of households and their location through a journey to work function; these households determine retail employment levels and location through a journey to shop function; another round of households are generated to work in the retail sector and are allocated by the journey to work function, and so on. The model has no time frame in which these adjustments occur. The model goes to equilibrium and generates an "instant" city. The feedback between households and employment is therefore, in effect, a simultaneous interaction.

The Lowry assumption that employment growth determines population growth has been challenged by Muth,²⁰ who presents an econometric model whose results indicate that the more important effect is that of population growth. However, an important element of the Lowry model is the distinction between basic and retail employment. Muth does not attempt to disaggregate these two types of employment in the work that he presents. More recently, Santini³⁰ estimated a model similar to Muth's in which special attention was paid to the distinction between export (basic) and local (retail) employment.

Santini's results were more compatible with Lowry's assumption than with Muth's empirical results. The spatial model presented below also can be logically related to the Lowry model's assumptions since its major air polluting class of employment is analagous to a Lowry type basic employment sector.

One of the faults of the Lowry model is that it ignores many important determinants of location by using an average propensity to travel typical to all work trips or shopping trips. It thus is a very aggregate model which ignores much of the variation in the propensity to (or, alternatively, value of) travel. Obviously, it also ignores the causes of this variation. Subsequent models based on the Lowry framework have found it desirable to attach "attractiveness" factors to zones in order to obtain more reasonable predictions. To date, no satisfactory method of determining these attractiveness factors has been devised.

3.2 STEINNES AND FISHER'S "ECONOMETRIC MODEL OF INTRAURBAN LOCATION"

An alternative approach has been taken in the econometric model of Steinnes and Fisher (here called S-F³³). In this approach, a distinction is made on the basis of type of employee or resident making a trip. Further, the relative attractiveness of two zones is also incorporated into the S-F model in the context of the value of the work trip. For example, in the S-F model a person might be an employee of a nonmanufacturing firm who had a preference (high utility) for a zone of residence in which public parks are amply supplied. A work trip between job and house near public parks has a high value for persons of this type and should cause a park accessibility variable in the nonmanufacturing employment equation to have a high coefficient which is statistically significant. Because it uses many such accessibility relationships, the S-F model is highly disaggregate in terms of the value of accessibility. By actually estimating the effect of certain exogenous factors which might affect relative attractiveness of zones to different groups of people, the S-F model and its derivatives may eventually provide useful information to Lowry type modelers attempting to determine attractiveness factors. Some of the factors tested by S-F as shifters of zone attractiveness are local taxes, parks, resident incomes, racial segregation, land use zoning, and federal institutional employment.

The S-F model is conceptually similar to the Lowry model since it also posits residential and employment location as being simultaneously determined by instantaneous feedback effects. However, in the S-F model, the exact nature of the simultaneous interaction is not specified a priori, while the Lowry model assumes positive interactions between residence and employment.

Although the S-F model does not specify the signs of the simultaneous interactions between employment and residence, a later version by Fisher and Fisher¹¹ (F-F) predicts negative values of accessibility to employment or residence. In six of eleven cases, their simultaneously estimated significant employment and resident accessibility variables are negative. This result clearly represents a conflict with the Lowry theoretical structure. The result also seems counter-intuitive.

3.3 THE "EMPIRIC ACTIVITY ALLOCATION MODEL"

The Empiric model is actually less a model than a set of computational techniques. While the Lowry and Steinnes-Fisher publications present some kind of explicit theoretical structure for the equations developed in their models, the Empiric publications use such measures as the t-statistic, coefficient of determination, and multiple correlation coefficient as the basis for inclusion of variables in equations. Simultaneous methods of estimation are used (two stage least squares) but no theoretical logic is presented for the equation structures used nor the shifter variables selected. In fact, the condition of identifiability (see Johnston¹⁶) of the simultaneous equations is satisfied simply because several independent variables prove not to be significant (and are therefore deleted) in a given equation. Econometricians recognize this as an improper application of simultaneous equations techniques. Further, the Empiric authors claim predictive accuracy by demonstrating a good fit of their estimates to the data on which the model is calibrated. Again, competent econometricians consider this to be an improper validation procedure.

Although no explicit statement of theory is made in the Empiric publications,^{26,36} the equation structure presented does imply certain theoretical positions. The Empiric authors do assert that coefficients of variables had

to satisfy certain logical restrictions, but they do not state what these logical restrictions are. Without a knowledge of the logic used, it is impossible for a reader to know whether a variable was excluded from an equation because of statistical insignificance or logical restrictions. Consequently, the Empiric models can only be said to have implied theoretical bases.

Among these implied theoretical bases, one notable characteristic of the Empiric equations is that employment growth influences population growth but no direct population on employment growth feedbacks occur. In total, the employment-population growth interactions are very minor. Like Lowry and S-F, the accessibility to employment influences population in a zone and vice-versa. Like S-F, the Empiric model uses disaggregation by type of employee or resident. However, the value of a trip is not incorporated.

Unlike Lowry and S-F, the Empiric model implies that trips other than work trips influence location. The social trip is allowed in the resident equations by including accessibility to other residents. The business trip or interindustry commodity trip is allowed in the employment equations by including accessibility to other employees. In the Washington version of Empiric, it appears that the logical sign of accessibility coefficients is positive, since no negative accessibility coefficients are presented. This is inconsistent with the Boston results in which numerous negative accessibility coefficients were obtained. Finally, the success of the utility variables, which are unique to this model, indicates that water and sewer hookups can be important determinants of growth.

It is apparent that the Empiric modelers went to extensive effort to obtain variables which would provide a good fit in terms of R^2 . By their own admission, many outlying data points were removed from the equations in order to improve R^2 values. In order to obtain eleven acceptable transportation accessibility variables, a total of three hundred and ninety-six accessibility variables were generated and tested. For utility services, three were used out of seventy five tested. There is little discussion of the reasons that certain kinds of variables work better than others and thus subsequent modelers cannot easily learn from the Empiric modelers' experience. Further, no criterion is presented for deleting outliers from the data, as subsequent modelers might also wish to do.

One more flaw in the Washington Empiric model is its selection of zone size. The Empiric model is a growth model and, as such, it should most carefully examine high growth zones. One way to use zone size to accomplish this is to use more, and thus smaller, zones in areas where the greatest future growth is anticipated. In a metropolitan area, highest growth locations will typically be found in peripheral suburban locations. Yet in the Washington Empiric model, these zones are relatively large in area and consequently smaller in number.

With all of its faults, the Empiric model must nevertheless be recognized as an accomplishment and contribution to the field of urban modeling. Of the models discussed here, it is the only applied planning model. It has generated projections which seem plausible to metropolitan policy makers. It demonstrates that econometric techniques can be used successfully for spatial modeling purposes. It adds to the list of works which show that accessibility is undoubtedly one of the most important determinants of urban spatial structure. It also adds a new set of variables based on utility services which appear to belong in urban spatial models.

Nevertheless, the model does not stand well against careful scrutiny and it should not be regarded as the last word in econometric modeling techniques. It has not yet been properly validated even though it has been so represented. It has been successfully represented as a model when, in fact, it is a set of techniques. This makes it difficult for those who wish to use the same techniques to estimate a model to explain to uninformed decision makers that the use of these techniques is not equivalent to covering the same ground as in prior Empiric work.

3.4 THE ADAPTED STEINNES-FISHER MODEL

Partly because of a lack of theoretical structure in the Empiric models, the model to be presented in this report is based on an adaptation of the S-F model structure. The major adaptation involves the examination of accessibility by mode. Where the S-F model has only a generalized accessibility measure, our adapted S-F model includes generalized, rail rapid transit, and commuter rail accessibility measures. The S-F model allows the modeler to use judgment in selecting those zone attributes which would be expected to shift the relative attractiveness of a zone. The model we construct includes

three unique variables of this type which perform extremely well in the employment equations. These variables include measures of waterway channel capacity, waterway dependable flow rates and recent commercial airport activity levels. Most major U.S. cities include waterways and busy airports. Significantly, the cities previously studied by the models discussed in this section (Pittsburgh, Chicago, Boston, and Washington) include major commercial airports, waterways, and in three of the four cases, major navigable waterways carrying substantial commodity shipments. Yet none of the models discussed incorporates these characteristics (nor do others examined, including Crecine¹⁰ and Ingram, Kain and Ginn¹⁵). To a large extent, these variables represent the local importance of interurban transfer points.

Because it is not consistent with the S-F structure to do so, this model does not include direct consideration of social trips or of business and industrial input-output linkages. Because of higher priority assigned to employment location in general and air polluter employment location in particular, the influence of utility hookups on residential location has been neglected.

The S-F model and this one are both static models simultaneous in employment and residence. Since the factors determining employment and population concentrations are of interest, zone sizes were reduced in the center city so that more observation points would be available in that area. This decision gave a much better resolution for rail rapid transit effects than would have been possible if zone size were held uniform at the typical suburban township size. Relative zone sizes are shown in Fig. 1.

As a means of summarizing the discussion presented above, Tables 1 and 2 have been prepared. Table 1 presents a general summary of attributes of the Lowry, Steinnes-Fisher, and Empiric Washington models in comparison with our Argonne model. Since the Argonne model focuses substantially on the effect of transportation infrastructure as a determinant of intraurban location, Table 2 is presented to compare transportation system attributes included in these four models. Note that the Argonne model examines the effect of accessibility in as much detail as the Empiric model, while incorporating an adapted S-F theoretical structure which accounts for the value of accessibility. It will also be shown later that the Argonne model incorporates and tests certain theoretical features of the Lowry model structure.

FIG. 1 CHICAGO STANDARD CONSOLIDATED STATISTICAL AREA:
DATA ZONES AVAILABLE AND ZONES USED.

Table 1. Summary and Comparison of Attributes of Models Examined in Text							
Model	Time Frame	Zone Descriptions	Methodology	Explicit Theory?	Simultaneous Resident and Employment Equations?	Exogenous Variables	Incorporates Value or Desirability of the Trip?
Lowry	Static 1960	Uniform Size: Complete Coverage	Simulation	Yes	Yes	Accessibility by Work or Shopping Trip; Density Constraints	No
Steinnes Fisher	Static	Variable Size: No Pattern: Incomplete Coverage	Econometric	Yes	Yes	Work Trip Accessibility by Type of Commuter; Taxes; Parks; Income; Segregation; Zoning; Institutional Employment	Yes
Empiric	Growth 1960-68	Variable Size: Smaller in Center: Complete Coverage	Econometric	No	Yes	Any Trip Accessibility by Mode; Base Year Residence and Employment; Zoning; Utilities	No
Argonne	Static 1970	Variable Size: Smaller in Center: Complete Coverage	Econometric	Yes	Yes	Work Trip Accessibility by Type of Commuter and Mode; Parks, Waterways; Airports	Yes

Table 2. Accessibility Considerations by Models in Text						
Model	Work Trip	Shopping Trip	Business Trip	Mode of Trip	Type of Employee or Resident	Interurban Trips or Shipments
Lowry						
Steinnes Fisher						
Empiric						
Argonne						

Thus the Argonne model is an integrative work drawing from and adding to three prior urban spatial models which were created for both theoretical and applied purposes.

4. THE ECONOMETRIC MODEL OF TRANSPORTATION INFRASTRUCTURE AS A DETERMINANT OF INTRAURBAN LOCATION

The Steinnes-Fisher article on which this model is based is composed of two employment equations and four residential equations. Employment is divided into manufacturing and nonmanufacturing. Resident workers are white or non-white and white collar or blue collar. In the S-F article only the residential equations are presented. Based on the residential equations alone, there is little difference in locational behavior by occupation but substantial differences by race do exist. Since the Argonne model was to be based on the same metropolitan area, Chicago, ten years later it was decided that the S-F result justified the use of only the racial breakdown in our equations. Once our project had committed itself to this decision, the Fisher-Fisher article¹¹ was published, including employment equations indicating that occupational breakdowns were indeed useful in the accessibility (called potential by S-F and F-F) variables. In spite of the F-F finding, the Argonne model employment equation results are substantially better than the F-F results, even without the resident occupational breakdown.

Based on the need to determine the causes of location of major immobile air pollution emitters (stationary industrial sources) it was decided that a third category of employment would be necessary for the Argonne model. This category was to be major air polluting manufacturing employment. Subsequent research by Santini²⁹ indicated that most Chicago area emissions occur at or near water-adjacent locations and that most emissions are from industries using large volumes of water. When major air polluting industries were divided into those using more than a billion gallons of water per establishment per year (water-users) and those using less (non water-users), it was found that the locations of water-users could be reasonably accurately predicted, while locations of non-water users did not show a pattern easily translated into an analytical format. It was assumed that these two classes of air polluting industry would differ greatly in their locational sensitivity to environmental regulation. Those industries clearly requiring large volumes of water appear to be spatially insensitive to air quality regulation. Consequently it would be expected that protection of the public from such industries could best be accomplished by control of the source or removal of receptors. Remaining non-water using industries might be more likely to move if local emission restrictions became severe.

If such an industry were in a populated area when it is not relatively expensive to be located in a rural area then policies causing movement of such industries might be more cost-beneficial than added control devices in existing locations.

The major water-using air polluting industries constitute the vast majority of manufacturing employment along the southwestern tip of Lake Michigan. The Gary-Hammond SMSA is primarily a result of the existence of these industries in this location. Further, in the Chicago SCA the water-using air polluters constitute sixty-six percent of the total air polluting employment along with an uncertain, but probably greater, majority of area emissions (uncertain because a complete Indiana emissions inventory was not available). Thus major water-using air polluting employment was used as the third employment category of the Argonne spatial model.

As a result of the above resident and employment disaggregation, the adapted Steinnes-Fisher formulation used here is a five equation model in which three employment classes are simultaneously estimated with two resident classes of endogenous variable. For exogenous variables the S-F formulation results in essentially three types. These are (1) aggregate accessibility to employment and residents of other zones, (2) employment and resident market shifter variables in a zone, and (3) aggregate accessibility to shifters of all other zones. Since there are three kinds of disaggregate accessibility defined in the Argonne model and five employment-residence classes, a total of 3×5 employment-residence accessibility variables are defined. While the S-F model has a total of fourteen employment and resident market shifter variables, our model uses only four. However, with the three types of accessibility instead of the one of S-F, the total of accessibility to shifter variables is 3×4 , which gives only two less accessibility shifters than used by S-F. In total there are five endogenous variables and thirty-three exogenous variables defined by the model structure, including two constant dummies.

4.1 THE MODEL

By using the employment, resident and shifter variables and constructing the accessibility variables from them, the adapted S-F model is constructed as follows:

$$E = F(R, \bar{R}, X_E, \bar{X}_R) + N_E \quad (3 \text{ equations}) \quad (1)$$

$$R = F(E, \bar{E}, X_R, \bar{X}_E) + N_R \quad (2 \text{ equations}) \quad (2)$$

where:

E is a 3 X 1 vector of numbers of employers,
 R is a 2 X 1 vector of numbers of residents,
 $\bar{R}$ is a 6 X 1 vector of accessibility to residents,
 $\bar{E}$ is a 9 X 1 vector of accessibility to employees,
 X_E is a 4 X 1 vector of exogenous employment market
 shifter variables, X_1 to X_3 plus a constant dummy,
 X_R is a 2 X 1 vector of exogenous resident market shifter
 variables, X_4 plus a constant dummy,
 $\bar{X}_R$ is a 3 X 1 vector of accessibility to exogenous resident
 market shifters,
 $\bar{X}_E$ is a 9 X 1 vector of accessibility to exogenous employment
 market shifters,
 N_E and N_R are random disturbances.

As in S-F, the accessibility variables are regarded as predetermined, allowing Equations (1) and (2) to be interpreted as a complete structural system, with the E's and R's endogenous. Equation (1) may be termed an employment location equation and Equation (2) a resident location equation. The equations seek to explain employment and residence location primarily as a function of public sector transportation capital investments in airports, highways, rail transit, commuter rail, and waterways.

4.2 ZONE DEFINITION AND SELECTION

The earliest stages of model development involved tests with most readily available data. This consisted of work based on data in the Suburban Factbook published by the Northeastern Illinois Planning Commission²¹. This is an excellent data source including employment, population, land use, and numerous other items. It completely describes the suburban areas of the Chicago SMSA. Data

is provided by township and by community. An important problem of the latter category is that community data is available only for communities of ten thousand or more population. Since there are several industrial suburbs containing major polluters but less than ten thousand residents the community data was inadequate for our purposes. It would also seem that this implies some deficiencies in the S-F Chicago area data since it is based on a sample of community data. In our data base the township was selected since it provides complete coverage of the land area in the suburbs. There should therefore be less errors of omission in this data base than in the S-F and F-F data.

The use of townships in the suburbs automatically defined zone boundaries over a large portion of the study area. In general the townships are relatively uniform in size. There are, however, a few exceptions where townships are relatively quite small. In these cases zones were aggregated to form more uniform zone sizes. Township data was also readily available for the Gary-Hammond SMSA from the Northwestern Indiana Regional Planning Commission, although it was not in a single, comprehensive document.^{24,25,27} The most difficult data to assemble, though readily available, was that for the City of Chicago. Employment and land use was available by square mile.^{6,23} Manufacturing employment checks were made by using several different sources of information.^{8,12,14,19} Population data was available by census tract.⁴⁶ It was necessary to define zone boundaries and construct aggregate variables by combining and comparing the above sources of data. Quarter square miles were used as a base and matched to census tract boundaries as nearly as possible. As discussed earlier, it was desirable to go to a smaller zone size within Chicago to maintain adequate resolution and to give a slightly higher weight in the regressions to areas where people are concentrated at the highest densities. Further, because of the emphasis of this study on the importance of waterways, zones were defined in such a way that they surrounded waterways rather than bounded them. (See Fig. 1 for zone characteristics). The decision to define a zone in this manner and the desire to include all of the 27 ft. deep Calumet River segment in one zone leads to the unusually shaped zones at the southern end of Chicago. This zone definition allows a consistent treatment of deep harbors along the lakeshore. Only zones bounding the lakefront have a waterway segment capable of handling a deep draft lake vessel.

The zone definition procedure resulted in available data with complete coverage of six Illinois counties and two adjacent Indiana counties. The next question to be addressed was whether all available zones should be included in an urban spatial model. It is doubtful that county boundaries defined over a century ago correspond to the present area of influence of the Chicago and Gary-Hammond urban centers. Theoretical monocentric models of an urban area lead one to expect a population density gradient as in Fig. 2 which drops from a maximum at the center to a rural density at the end of the urban center's market influence. In the absence of drastic geographic irregularities this urban area of influence should be roughly circular and centered at the central business district (CBD). In the case of a dual centered metro area such as Chicago-Gary, one expects two overlapping semicircular patterns bounded by the lakefront. Given this expectation the difficulty is to identify where the urban-rural fringe is located.

The method of identifying the fringe used here was to examine the growth pattern implications of a flattening density gradient. As illustrated in Fig. 2, this graphical exercise implies that the highest growth rate in a prior decade will be at the point (or in the area) where the urban rural fringe was in the beginning of the decade. Slightly beyond the high growth locations the end of decade urban fringe will be found.

In Fig. 3 this shifting urban density gradient paradigm has been applied to the Chicago metropolitan area. With the exception of two zones the pattern of growth is very compatible with expectations developed in Fig. 2. The two exceptional zones are easily explained. Each of them is adjacent to a satellite suburb of Chicago on the side opposite of Chicago. It is consistent with classical theory that growth in secondary markets under the influence of a larger market would occur on the side of the secondary market which is opposite the central area of the larger market.⁵⁰ Thus, the high growth zones in Fig. 3 adjacent to Aurora and Joliet are actually beyond the Chicago urban fringe. Consequently, the study area boundary has been drawn to exclude these zones. The study area boundary is also generally drawn to be one zone beyond zones classed as high growth since this is called for by the shifting urban density gradient paradigm.

A second experiment used to aid the decision on zone boundary definition was to plot density directly. This plot is shown in Fig. 4 and generally matches

FIG. 2 THE SHIFTING URBAN DENSITY GRADIENT PARADIGM

NOTE: CHICAGO TREATED AS SINGLE ZONE; INDIANA VALUES BASED ON 1970-73 DATA

FIG. 3 THE PATTERN OF 1960-1970 POPULATION GROWTH RATES

FIG. 4 POPULATION DENSITY IN 1970

the density gradient expected using a monocentric city model. Chicago's satellite cities of Chicago Heights, Joliet, Aurora, Elgin, and Waukegan show up as higher density zones than most adjacent zones. They also are aligned in a roughly semicircular pattern around Chicago's Loop at locations where the Chicago urban fringe is expected to be. For this reason and because these cities include major polluting industries, the study area boundary has been drawn to include these satellite cities. Except in the Northwest suburbs the study area boundary generally includes all of those zones developed at greater than rural densities. As will be illustrated later, this northwestern area is probably built up at a greater distance from the Loop than other suburban townships because commuter rail service is provided to most of these zones. The high growth areas shown in Fig. 3 are the result of recent automobile based density gradients rather than older commuter rail based density gradients. Consequently, a study area boundary based on these zones is more current than one based on the density patterns of Fig. 4. It is encouraging, however, to note the broad compatibility between study area boundaries which might result from either a growth or density analysis.

In a final experiment the locations of high employment per capita clusters were determined. Since employment is generally more clustered than population in an urban area one expects to find highest employment/population ratios close to the business center with a consistent decline out to the "bedroom suburban" areas in which little industry or business is located. At or beyond the urban-rural fringe there must be self-sufficient employment centers - i.e. other cities and towns distributed fairly evenly throughout an agricultural landscape. These rural towns should show up as occasional high points in the employment/population ratio surface. In general, the employment/population ratio surface shown in Fig. 5 matches this expected pattern. A ring of bedroom suburbs surrounds the Loop centered employment cluster. The relatively self-sufficient satellite cities of Chicago Heights, Joliet, Aurora, Elgin, and Waukegan show up at the previously defined urban fringe, as well as some additional zones along the study area boundary drawn from Aurora to Elgin to Waukegan. Beyond the study area boundary self-sufficient rural towns cause occasional high points in the ratio surface. The dual centered nature of the Chicago-Gary SCA clearly shows up, with employment clusters anchored by Gary and Chicago's Loop.

The result of our careful zone definition and selection process is as follows:

- (1) A study area including Chicago, Gary and Chicago's satellite cities is defined,
- (2) All but three 1970 major water-using air polluters are included in the study area (the three excluded are adjacent to and south or southwest of Joliet),
- (3) Zones are generally similar in size, even though the smallest and largest zones differ in area by an order of magnitude,
- (4) The study area boundary is selected in such a way that nonurban zones do not confound the determination of urban spatial structure, and
- (5) Individual zone boundaries selected, when possible, accurately reflect the expected cause and effect relationships to be modelled. (e.g. channel capacity)

4.3 VARIABLE DEFINITION AND CONSTRUCTION

In this section we examine the four classes of variables in the model, as presented in equations (1) and (2). The development of and logic behind variable definition and construction is discussed. The order of discussion will be slightly changed from that presented in equations (1) and (2). We examine the endogenous variables, R and E ; the exogenous market shifter variables, X_E and X_R ; and finally the accessibility variables, $\bar{R}$, $\bar{E}$, $\bar{X}_E$, and $\bar{X}_R$. We will only discuss those variables included in the model. The data base compiled for this research is more extensive than this section will indicate. A more thorough discussion of the data base and of variable construction is presented in Appendix A.

4.3.1 Endogenous Variables

There are five endogenous variables in the model. The residential variables are White Population, R_1 , and Black Population, R_2 . Black population is actually nonwhite population, being the residual of total population minus white population. Both of these variables are based on U.S. Census data, but are usually based on secondary sources. For the Chicago area suburbs the Suburban Factbook²¹ was used. For Indiana a reproduction of census data was used.²⁵ For Chicago, since we had developed our own zone definitions, it was necessary to construct these variables from original census tract data.⁴⁶

The three employment variables were obtained from multiple sources. The total manufacturing employment ($E_1 + E_2$) and the nonmanufacturing employment (E_3) were aggregated from more detailed classes. Total manufacturing includes those categories listed in the Suburban Factbook as (1) Mining, Quarrying and Contract Construction, (2) Transportation, Communication and Utilities, and (3) Manufacturing. Nonmanufacturing employment, E_3 , consists of all other employment categories. In addition to the Suburban Factbook, other sources consulted include Where Workers Work in the Chicago SMSA¹²; a Northeastern Illinois Planning Commission "Employment Survey by Quarter Square Mile"²³, the Northwestern Indiana Regional Planning Commission Employment Survey Technical Report²⁷, and County Business Patterns, 1970: Indiana⁴⁴. In several cases these sources were compared to one another. When conflicts arose third parties were consulted as to the most reliable data source. In most cases the results compared very well. However, based on our experience with this and other data obtained we do not believe that more than three significant figures exist for most data numbers. Consequently, the results presented for our regressions will be listed only to three significant digits.

From total manufacturing, the remaining two employment variables are constructed. The major Water-Using Air Polluting Employment category, E_1 , is constructed from additional sources of data, including data from Commonwealth Edison⁸, State of Illinois Emissions Inventories¹⁴, a study on Effluents and Water Quality in the Calumet Area of Lake Michigan³², and the 1967 Census of Manufacturers: Water Use in Manufacturing⁴⁵. This variable is then subtracted from total manufacturing employment in order to obtain Other Manufacturing Employment, E_2 .

Classification of major water using air polluters was done at the four digit Standard Industrial Classification (SIC) level. If, on a national basis, an industry uses over a billion gallons of water per establishment per year then it is called a major water user. If a firm has the potential to emit over 100 lbs/hr. of particulates, sulfur oxides, nitrogen oxides hydrocarbons, or carbon monoxide then it is a major air polluter. The four digit SIC's from which the Chicago-Gary SCA major air polluting firms come are listed in Table 3. Note that not all firms in a given four digit SIC are included in E_1 .

The primary objective of this modelling effort is to determine the locational attributes of major air polluters. For reasons discussed earlier, it

TABLE 3. STANDARD INDUSTRIAL CLASSES ADMISSABLE TO WATER-USING,
AIR POLLUTING EMPLOYMENT, E₁^a

SIC	TITLE
2046 b	WET CORN MILLING
2621 c	PAPERMILLS, EXCEPT BUILDING PAPER
2813 b	INDUSTRIAL GASES
2818 c	INDUSTRIAL ORGANIC CHEMICALS, NEC.
2819 c	INDUSTRIAL INORGANIC CHEMICALS, NEC.
2833 b	MEDICINALS AND BOTANICALS
2871 b	FERTILIZERS
2892 b	EXPLOSIVES
2911 b	PETROLEUM REFINING
3295 b	MINERALS GROUND, OR TREATED
3312 b	BLAST FURNACES AND STEEL MILLS
4911 b	POWER PLANTS

^aAt least one source in the SIC has been found to be a major polluter (emit over 100 lbs./hr. of particulates, SO₂, NO₂, HC, and/or CO) on an Illinois or Indiana emissions inventory.

^bSource(s) identified as a major air polluter in the study area.

^cPresent in the study area but no study area source is presently identified as a major air polluter.

was decided to focus attention on major water-using air polluting industry. A second reason for focusing on these industries in their energy intensive-ness. Water is used primarily for cooling purposes in these industries. Cooling is required because of combustion of large amounts of fuel. In fact, the three most energy intensive industries (power plants, petroleum refineries, and steel mills⁴) constitute over ninety percent of the employment in this category. Thus the results should be enlightening not only for air pollution purposes but also for energy consumption purposes.

Two sets of data were established for E_1 . The first was based on the State of Illinois' uncontrolled emissions inventory of 1974 and the second was based on a similar controlled emissions inventory. Campbell and Santini³ establish that the two inventories are very similar, but that some industries brought under control drop down in rank on the controlled inventory, as one would expect. It was decided that the uncontrolled emissions inventory would be used in the model presented here since it would give a better idea of where pollution control costs have been, or must be, absorbed by industry. Further, in theory, an uncontrolled emissions inventory will give a better idea of which industries move. This might prove useful in later studies. On a controlled inventory an industry could drop off the list either because it moved or because it applied control technology.

Particularly close attention was paid to the accuracy of location and level of employment in category E_1 . In addition to the employments sources listed above, maps were consulted to verify location (see Refs. 37 to 40). When inconsistencies were found, careful cross-checks were made. Frequently telephone calls or letters were necessary to insure the accurate determination of both location and level of employment. A spatial description of the employment concentrations in this class of industry is given in Fig. 6.

4.3.2 Exogenous Variables - Market Shifters

As can be seen in Fig. 6 and as one would expect as a result of the definition of E_1 , there is a clear association between waterways and E_1 . This relationship had already been observed by Santini²⁹ in his examination of patterns of location of air polluting industry in the State of Illinois. Campbell and Santini then established that, in addition to the use of the waterways as a location where water might be consumed, major air polluting

FIG. 6 CONCENTRATIONS OF MAJOR WATER USING AIR POLLUTING INDUSTRIAL EMPLOYMENT

industries use the Chicago area waterway system for substantial shipments of raw materials and products. It was noted that the magnitude of shipments via Lake Michigan is substantially greater than along the inland waterways. To a large extent this difference is a result of the greater depths available to Great Lakes vessels at the deep harbors along the lakefront. In order to establish the exact effect of channel depth on vessel and channel capacity, Braid and Santini² regressed various integer powers of vessel draft against vessel capacity, obtaining the surprising result that vessel capacity is a function of vessel depth to the fifth power. A power of three or four seemed more likely on a priori grounds. Due to the unexpected result, Braid and Santini conducted thorough checks on the validity of their regressions, but found no strong empirical reason in favor of another integer power of depth. It is comforting to note, however, that the regression results presented later do not become significantly different or poorer when the third or fourth power of depth is used as an index of channel capacity (see Appendix B).

The channel capacity measure, tends to give a very heavy weight to the deep harbors at the lakeshore. (See maps and charts in Refs. 37 to 40.) To a large extent this is appropriate since the vast majority of Chicago SCA tonnage comes into these harbors in the form of raw material for the steel industry. Further, substantial shipments of refined petroleum products and grains are exported from these lakefront deep harbors (See Table 4). The heavy weight assigned to the lakefront by the channel capacity measure is balanced to a certain degree by the dependable water flow variable. This variable increases in value as one moves away from Lake Michigan toward Joliet. (See Fig. 7 and Ref. 22.) The increases in dependable flow are not substantially influenced by precipitation induced runoff. The major increments in flow rates occur downstream of Chicago's massive sewage treatment plants and at junctions of waterways. The total dependable flow in the Chicago River, Sanitary and Ship Canal, Cal-Sag Channel, and Des Plaines River below Joliet is primarily a result of the total allowable water withdrawal from Lake Michigan and the placement of sewage treatment plants treating the water after it has been used by the public. (The Fox River has a very small flow relative to the above waterways.)

The variation in development along the banks of the waterways shown in Fig. 6 is partly a result of the fact that some of the riverbanks and lakeshores

TABLE 4 CHICAGO SCSA WATERWAYS FREIGHT TRAFFIC, 1973
(Thousands of Short Tons) (Waterborne Commerce of the U.S., 1973)

COMMODITY CLASS	INDUSTRIAL GROUP AND COMMODITY	ILLINOIS RIVER		LAKE MICHIGAN		INTERNAL		REGIONAL TOTALS		
		IMPORTS	EXPORTS	IMPORTS	EXPORTS	LOCAL	TOTAL	LOCAL/TOTAL	NET EXPORTS	NET IMPORTS
	<u>Power Plants</u>									
1121	Coal & Lignite	5427	0	0	5455	1	10983	.000	28	
2915	Residual Fuel Oil	2162	165	0	558	1039	3924	.265		1439
	<u>Stone Based Products</u>									
1442	Sand Gravel & Crushed Rock	2186	334	7	1	1873	4401	.426		1859
	<u>Grain Processing & Storage</u>									
0103	Corn	60	227	0	1540	58	1885	.031	1707	
0111	Soybeans	38	111	0	889	26	1064	.024	962	
2049	Grain Mill Products	0	236	0	769	0	1004	.000	1004	
	<u>Steel</u>									
1011	Iron Ore and Concentrates	0	0	31163	0	118	31281	.004		31163
1411	Limestone	0	0	8130	0	25	8155	.000		8130
3313-7 and 3319	Iron and/or Steel Products	317	1250	1195	137	46	2945	.016		125
	<u>Petroleum Refining</u>									
2911	Gasoline	117	196	0	1770	241	2324	.104	1849	
2914	Distillate Fuel Oil	250	126	0	1287	727	2390	.304	1163	
	<u>Chemicals</u>									
281	Chemical Products	1215	236	101	51	19	1622	.012		1029

FIG. 7 WITHDRAWAL AND DIVERSION OF LAKE MICHIGAN WATER IN COOK COUNTY
(Millions of Gallons Per Day, 1961; From [21])

are not available for industrial development. Much of the lakefront in the City of Chicago is reserved for public use. A significant portion of the Cal-Sag Channel is surrounded by a Forest Preserve. Such factors have been taken into account in the Water Flow Index, X_1 , and Channel Capacity Index, X_2 . Both variables are a result of multiplying the characteristic of interest (channel capacity or water flow) by the miles of shoreline available for private use. These variables therefore, incorporate the preemption of lands desirable for industrial use by competing public uses. (See Appendix A).

The airport activity variable was constructed and added to the model because of prior knowledge that O'Hare Airport had induced extensive light industrial development in its vicinity. O'Hare is also a major employer in its general area. It falls in the transportation employment category which, in turn is included in our Other Manufacturing Employment, E_2 , variable. There also is a cluster of manufacturing employment near the now relatively inactive Midway Airport. It seems likely that airport activity directly causes more E_2 employment by its activity and indirectly causes more E_2 employment because of shipments made by air by light industry. Another factor is the compatibility of industry with noisy airport environments. In order to incorporate the historical importance of Midway, an Average of Air Passengers in the Prior Decade, X_3 , was constructed by taking the mean of 1960 and 1970 passenger enplanements^{42,43}. This variable accounts for the fact that Midway was still active in 1960 but the variable is still dominated by O'Hare activity levels. Passenger enplanements or tons of freight shipped are equally good measures of airport activity since they are nearly perfectly correlated. (Airport locations are shown in Fig. 8.)

The final market shifter variable, Land Area Devoted to Public Parks, X_4 , is a residential market shifter rather than an employment market shifter such as X_1 , X_2 , and X_3 . It incorporates a combination of two desirable attributes of public parks, land area and Lake Michigan shoreline. The variable attempts to incorporate the Steinnes-Fisher and Fisher-Fisher finding that park services and shorefront locations are both attractive to potential zone residents. It consists of a sum of area of park land in square miles and length of Lake Michigan shoreline devoted to city or county public parks in linear miles. It essentially weights Lake Michigan shoreline parks much more heavily than remaining parks. In addition to the Suburban Factbook, data for this variable was obtained from a Chicago Department of Development and

Planning 1970 land use inventory⁶ and an "Eight Category Land Use Summary for Townships" by the Northwestern Indiana Planning Commission²⁴.

4.3.3 Exogenous Variables - Accessibilities

Three types of accessibility by mode are incorporated in this model. A General (G) accessibility is defined which depends only on the magnitude of the variable to which accessibility is defined and airline distance to the zones where the variable is measured. A Rail Rapid Transit (T) accessibility to a variable is defined which depends on the variable to which accessibility is assigned, transit system distance between zones and number of stations per zone in both origin and destination zones. The third accessibility, Commuter Rail (C) accessibility is a function of the variable to which accessibility is assigned, commuter rail systems scheduled travel time between zones, frequency of on time service, and number of stations per zone in both origin and destination zones.

The accessibility to a variable, Y, for all other zones k', from a zone of origin, zone k is defined as

$$\bar{Y}_{ki} = \sum_{k' \neq k} Y_{k'} / t_{kk'i} \quad i = G, T, C \quad (3)$$

where $t_{kk'i}$ is the travel cost for mode i from zone k to zone k'.

We may go on to define each of the three travel cost functions $t_{kk'G}$, $t_{kk'T}$, and $t_{kk'C}$ as follows:

$$t_{kk'G} = d_{kk'}^2. \quad (4)$$

where $d_{kk'}$ = airline distance between zones k and k', from Refs. 21 and 27.

$$t_{kk'T} = r_{kk'T} / s_{kT} s_{k'T} \quad (5)$$

where $r_{kk'T}$ = rail transit system distance between zones k and k', from Refs. 5, 7 and 13.

s_{kT} and $s_{k'T}$ = numbers of rail transit A and B stops in zone k and k' from Refs. 5, 7 and 13.

$$t_{kk'C} = r_{kk'C} / (s_{kC} s_{k'C} f_{kC} p_C) \quad (6)$$

where

- $r_{kk'C}$ = commuter rail inbound rush hour (7:00 - 9:00 loop arrival time) scheduled travel time between zones k and k' as of 1960, from Ref. 9.
- s_{kC} and $s_{k'C}$ = number of commuter rail stations in zone k and k' respectively as of 1960, from Ref. 9.
- f_{kC} = average frequency of loop bound rush hour trains in zone of origin, k, as of 1960, from Ref. 9.
- p_C = percent of trains arriving on time as of 1975, from Ref. 31.

Although it may appear that the travel cost functions are inconsistent in the quality of definition this is not an empirical problem. From the point of view of regression analysis the objective of variable construction is to capture most of the relevant variation with a minimum of effort. There is little sense in adding empirical detail to the theoretical variable if, for example, ninety percent of the true variation of the perfectly defined variable is already accounted for, while any other variable's construction can account for no more than eighty percent of its theoretical true variation. In other words, adding detail is a waste of time if it has no effect on the results.

Unfortunately, one cannot know for certain when too much detail is used unless one has already included too much detail. In this case we attempted to use judgement developed from prior work with regression analysis to help in selecting the necessary level of detail for the travel cost functions. In prior work, Santini²⁸ has already shown that airline distance is a close substitute for highway system travel times for a variety of network configurations and congestion situations. Baxter and Lenzi¹ indicate that airline distance may often be an adequate proxy for highway travel time in the absence of unusual geographical constraints. Competing systems such as rail rapid transit and commuter rail offer levels of service of considerably greater spatial variation than the highway system. In such a case, airline distance as proxy for highway travel time should adequately account for the relative effects of highway vs. rail service. The substantial and non-overlapping spatial variations in level of service by rail rapid transit and commuter rail are illustrated in Fig. 8 and Fig. 9. These compare with more uniform patterns of general highway accessibility (not illustrated).

FIG. 8 RAIL RAPID TRANSIT LEVELS OF SERVICE

FIG. 9 COMMUTER RAIL LEVELS OF SERVICE

In the Lowry model, residence to work trips were estimated to drop off with distance inversely to distance raised to the power 1.33. In this model general travel cost is also assumed to be inversely proportional to distance raised to a power. The exponent selection procedure involved a comparison of results based on the integer powers one and two. A power of two was determined to provide best results. Thus, the general travel cost function here increases as a function of distance squared.

Our expectation is that accessibility has a lagged effect on location decisions. As a consequence, the ideal accessibility variables for the model would have been based on some prior population, employment, and travel cost levels. Unfortunately, the acquisition of population and employment data for our zones for 1960 was not practical. Therefore, the accessibility variables are based on prior travel cost functions, $t_{kk,i}$ but present Y_k values.

This accounts for the fact that our rail rapid transit travel cost function is based on the number of stops/station as of 1964. The decision to include 1964 rather than 1960 transit service meant that the Skokie Swift serving Niles township was taken into account. The 1964 service does not include the Dan Ryan line, which was completed in 1968. Another problem with the rail rapid transit and commuter rail variables was what should be done with the Illinois Central Commuter Railroad. This railroad is electrified, has a frequency of trains more similar to the CTA rail transit system than to other commuter railroads, and is the only commuter rail line which provides more service to the city than the suburbs. As a consequence it was decided to treat the Illinois Central as an element of the rail rapid transit variable. This is an important distinction in the model which provides much better and more plausible results. It is also a distinction relevant for transportation planning since the success or failure of new rail transit may be a function of whether and where it provides service like a commuter railroad or a rail rapid transit system. A general indicator, s_{kT} , of the level of service provided by the rail rapid transit system is provided in Fig. 8. This figure shows fairly clearly that the high train and stop frequency rail rapid transit system is designed to serve the City of Chicago.

In Fig. 9, a similar level of service index for commuter rail is shown. This figure shows the results of multiplying s_{kc} by f_{kc} . It is clear from

this figure that the commuter rail system provides its highest frequency and coverage of service to suburban locations and provides only spotty service within the city. Where competing rail rapid transit service is available few commuter rail stations are provided. This allows the commuter railroads to offer quicker access to the Loop for their suburban customers. Note also that the highest levels of service are provided to the western and northern suburbs rather than to the more heavily industrialized southern locations. One of the railroads shown on Fig. 9, the New York Central going to Gary and Hobart has since ceased to operate. Currently, the South Shore, the railroad along the southern Lake Michigan shore, is also planning to go out of business. Apparently those commuter railroads passing through industrialized areas no longer have enough nonmanufacturing employees headed for the Loop to remain in business.

It is informative to compare Fig. 9 to Fig. 3. We remarked earlier that the growth pattern of Fig. 3 probably represented an automobile rather than commuter rail oriented pattern. The comparison of commuter rail level of service to high growth areas tends to confirm this assertion. Note that, of the fifteen study area high growth zones in Fig. 3, three are not served by commuter rail at all, nine are served at the lowest level by commuter rail, only three are served at an intermediate level by commuter rail, and none are offered the highest non Loop level of commuter rail service.

As a final observation on the character of the rail variables we consider the degree of integration of the system. The rail rapid transit system provides accessibility not only to the Loop but also through it. Black domestic workers living on the South Side of Chicago can travel through the Loop and all the way north to Winnetka to find employment by riding on the same system. A person cannot take any single commuter railroad through the Loop and out the other side. A change of trains is necessary. The present rail rapid transit and commuter rail accessibility variables incorporate these attributes.

When the three travel cost functions of equations (4), (5), and (6) are combined with the nine previously discussed endogenous and market shifter variables one obtains twenty-seven accessibility variables which theoretically should enter into the model. These variables are distinguished by adding a bar overhead and a mode of accessibility subscript, G, T, or C. Thus, for example there will be three accessibility measures constructed

from Nonmanufacturing Employment, E_3 , as follows:

$\bar{E}_{3G}$ = General Access to Nonmanufacturing Employment

$\bar{E}_{3T}$ = Rail Transit Access to Nonmanufacturing Employment

$\bar{E}_{3C}$ = Commuter Rail Access to Nonmanufacturing Employment

One of the accessibility variables, $\bar{X}_{3T}$, though defined, has a value of zero everywhere since no rail transit line serves an airport. Otherwise all accessibility variables have been constructed and tested in the model but several are excluded because of statistical insignificance.

4.4 A Priori Expectations

The previous discussion on exogenous shifter variable definition and construction indicated fairly clearly what the priori expectations for X_1 through X_4 are. Let us quickly review these expectations.

X_1 : the Water Flow Index is expected to positively shift the demand for Water-Using Air Polluting Employment, E_1

X_2 : the Channel Capacity Index is expected to positively shift the demand for E_1

X_3 : the Average Air Passengers in a Prior Decade (Airport Activity) is expected to positively shift the demand for transportation employment and light industrial employment, both in other manufacturing, E_2

X_4 : the Land Area Devoted to Public Parks is expected to positively shift the demand for residences by White Population, R_1 , and Black Population, R_2

Thus variables X_1 through X_3 will enter into the vector of employment equations E_1 through E_3 , while variable X_4 will enter into the residential equations R_1 and R_2 . Consistency with the semistructural system of Steines and Fisher then implies that constructed variables denoting accessibility to X_1 through X_3 enter into the residential equations R_1 and R_2 . Similarly, accessibility to X_4 enters into the employment equations E_1 through E_3 .

The value of accessibility between a class of residents and employment should, in part, be a function of the likelihood of the two classes being matched in terms of skill capabilities and requirements. For example, in the case of nonwhite males in the Chicago SMSA their proportion of total male employment in the steel industry is 0.33. For employment as a whole nonwhite males held only a fraction of 0.17 of the male held jobs in 1970.⁴⁷ Where nonwhite males are employed in the steel industry, they and their families will be more likely to live near the steel industry. Since steel constitutes the vast majority of employment in the E_1 category one may expect a positive association between E_1 and R_2 variables. This includes the simultaneous E_1 on R_2 relationship, the $\bar{R}_2$ on E_1 relationships and the $\bar{E}_1$ on R_2 relationships. An important point here is that the steel industry historically has been a major determinant of growth in the Southern Chicago-Gary Lake Michigan area. If blacks more readily found employment in the steel industry than elsewhere in the economy then Chicago's South Side Negro Ghetto and Gary's substantial black population are a logical result of black job opportunities as much as segregated housing opportunities.

A second possible influential element in the location of nonwhites may be an absolutely and proportionately greater opportunity for employment in and around Chicago's Loop. For example, in the extremely Loop centered Census Bureau job categories of Postal Service and Federal Public Administration, nonwhites hold 42% of the jobs. This compares to a total percentage of jobs held equal to 19. Nonwhite females actually hold a majority of female held jobs in this category⁴⁷. Although raw data has been collected to test the importance of Loop centered Federal and State employment the time and conceptual constraints of this project have caused us to neglect this particular opportunity. However, it does seem worth pointing out that the location of the South Side Negro Ghetto in Chicago may largely be a result of very rational choices by blacks based on the probability of obtaining jobs in the steel industry to the south or government services to the north.

It is obvious from the layout of the rail rapid transit and commuter rail systems that their design is intended to provide service to the Loop. Since the Loop is by far the most substantial employer in the nonmanufacturing category one expects rail systems to be most important (i.e. more frequent significant coefficients) when associated with nonmanufacturing employment, E_3 .

It is thus hypothesized that the effects of $\bar{E}_{3T}$ and $\bar{E}_{3C}$ on R_1 and R_2 will be positive. Conversely the impact of $\bar{R}_{1T}$, $\bar{R}_{1C}$, $\bar{R}_{2T}$ and $\bar{R}_{2C}$ on E_3 is also likely to be positive.

By contrast automobiles are relatively more frequently used in work trips to manufacturing firms. Since manufacturing employment tends to be much more broadly dispersed it does not lend itself well to public transit ridership, especially by rail. Thus a positive and frequently significant association is expected between general (auto or bus) accessibility and E_1 or E_2 based variables. Expected positive effects are for $\bar{R}_{1G}$, and $\bar{R}_{2G}$ on E_1 and E_2 , as well as for $\bar{E}_{1G}$ and $\bar{E}_{2G}$ on R_1 and R_2 .

A final a priori expectation relates to the level of significance of variables. As mentioned earlier, the Lowry "Model of Metropolis" assumes that certain industries are insensitive (within an urban area) to the location of labor supplies. For these industries other intraurban and interurban customer and supplier relationship are assumed to dominate the choice of location in the urban area. In the process of developing the data base for the water-using air polluters it became apparent that there was a good chance that this hypothesis would hold for these industries. Linneman's paper¹⁷ demonstrated that most of these industries are also exporters from the Chicago SMSA, satisfying a criterion for classification of the E_1 industries as Lowry-type basic industries. Thus a Lowry based a priori expectation would be that the accessibility to residents and resident variables in the E_1 equation will be insignificant.

A summary of these expectations and equation structure follows.

$$(7) \quad E_1 = f_1(\underbrace{R_1, R_2, \bar{R}_{1G}, \bar{R}_{2G}, \bar{R}_{1T}, \bar{R}_{2T}, \bar{R}_{1C}, \bar{R}_{2C}}_{\text{All coefficients insignificant}}, \bar{X}_1, \bar{X}_2, \bar{X}_3, \bar{X}_{4G}, \bar{X}_{4T}, \bar{X}_{4C}) + u_1$$

$$(8) \quad E_2 = f_2(R_1, R_2, \bar{R}_{1G}, \bar{R}_{2G}, \bar{R}_{1T}, \bar{R}_{2T}, \bar{R}_{1C}, \bar{R}_{2C}, \bar{X}_1, \bar{X}_2, \bar{X}_3, \bar{X}_{4G}, \bar{X}_{4T}, \bar{X}_{4C}) + u_2$$

$$(9) \quad E_3 = f_3(R_1, R_2, \bar{R}_{1G}, \bar{R}_{2G}, \bar{R}_{1T}, \bar{R}_{2T}, \bar{R}_{1C}, \bar{R}_{2C}, \bar{X}_1, \bar{X}_2, \bar{X}_3, \bar{X}_{4G}, \bar{X}_{4T}, \bar{X}_{4C}) + u_3$$

$$(10) \quad R_1 = g_1(E_1, E_2, E_3, \overset{+}{E}_{1G}, \overset{+}{E}_{2G}, \bar{E}_{3G}, \bar{E}_{1T}, \bar{E}_{2T}, \overset{+}{E}_{3T}, \bar{E}_{1C}, \bar{E}_{2C}, \overset{+}{E}_{3C}, \overset{+}{X}_4, \\ \bar{X}_{1G}, \bar{X}_{1T}, \bar{X}_{1C}, \bar{X}_{2G}, \bar{X}_{2T}, \bar{X}_{2C}, \bar{X}_{3G}, \bar{X}_{3T}, \bar{X}_{3C}) + e_1$$

$$(11) \quad R_2 = g_2(\overset{+}{E}_1, E_2, E_3, \overset{+}{E}_{1G}, \overset{+}{E}_{2G}, \bar{E}_{3G}, \overset{+}{E}_{1T}, \bar{E}_{2T}, \overset{+}{E}_{3T}, \overset{+}{E}_{1C}, \bar{E}_{2C}, \overset{+}{E}_{3C}, \overset{+}{X}_4, \\ \bar{X}_{1G}, \bar{X}_{1T}, \bar{X}_{1C}, \bar{X}_{2G}, \bar{X}_{2T}, \bar{X}_{2C}, \bar{X}_{3G}, \bar{X}_{3T}, \bar{X}_{3C}) + e_2$$

5. EMPIRICAL RESULTS

The coefficients of the employment equations, as estimated by three stage least squares (3SLS) and ordinary least squares (OLS) are presented in Tables 5 and 6. The coefficients of the resident equations by 3SLS and OLS are presented in Table 7. The OLS results are presented for comparative purposes only. Based on the theoretical model of Equations (7) through (11), simultaneous equations techniques are required for valid estimates of coefficients (see Johnston, p. 157, Ref. 16). The full information technique of three stage least squares used here is one of the better simultaneous estimation methods. All discussion of coefficients will be based on the 3SLS estimates.

The model presented in Tables 5 through 7 was developed from Equations (7) through (11) in the following manner. First OLS regressions including all variables were run. Exogenous variables were deleted from the OLS regressions by starting with variables with lowest t-values consistently below 1.0 in all equations and deleting variables until regressions could be run with the statistical package available. A 3SLS model was then developed in which every included exogenous variable coefficient had at least one t-value greater than 1.4. In speaking of at least one t-value greater than 1.4, we refer to the t-values of the three coefficients of a variable in the employment equation vector or of the two coefficients of a variable in the residence equation vector. Thus, for example, if a variable has a t-value greater than 1.4 in the E_2 equation it is also included in the E_1 and E_3 equations, consistent with the definition of variables affecting the employment vector or the resident vector. Variables earlier deleted by OLS and 2SLS were returned to 3SLS equations in a piecewise manner to insure that they continued to have insignificant coefficients when estimated simultaneously. None proved to have any t-value as great as 1.4. This process of deletion of least significant variables led to the elimination of all constant dummy variables from the model. Time restrictions kept us from adding capacity to the statistical package so that the less significant exogenous variables could be included in the model.

This process of model refinement was followed because excessive exclusion of variables from an OLS model is known by theory to cause biased coefficient estimates for prediction. Although no proof has been offered this is

Table 5. Employment Location Equations, 1970, Estimated by Three-Stage Least Squares, Regression Coefficients^a (Absolute t-Values in Parentheses)

Dependent Variables (Persons)	Water Using, Air Polluting Manufacturing, E_1	Other Manufacturing, E_2	Non- Manufacturing E_3
Right-Hand Variables			
White Population, R_1	b	b	b
Black Population, R_2	0.0129 (1.36) +	b	0.0893 (2.00)*
General Access to White Population, R_{1G}	b	0.598 (5.87)* +	0.153 (1.72)
Rail Transit Access to White Population, R_{1T} ($\div 10^3$)	-0.0668 (-3.70)*	0.256 (2.78)*	1.02 (12.87)* +
Rail Transit Access to Black Population, R_{2T} ($\div 10^3$)	-0.912 (-2.75)*	-2.11 (-1.22)	-3.42 (-2.24)*
Commuter Rail Access to White Population, R_{1C} ($\div 10^3$)	-2.59 (-2.54)*	b	-6.01 (-1.47)
Commuter Rail Access to Black Population, R_{2C} ($\div 10^3$)	53.0 (5.35)* +	b	88.2 (2.11)* +
Water Flow Index, X_1	0.296 + (3.00)*	0.659 (1.37)	b
Channel Capacity Index, X_2	19.2 (19.00)* +	8.60 (1.66)	6.99 (1.56)
Ave. Air Passengers in Prior Decade, X_3 ($\div 10^3$)	b	4.86 (4.14)* +	1.67 (1.69)
General Access to Park Land, X_{4G}	b	-7140 (-2.32)*	4280 (1.62)
Rail Transit Access to Park Land, X_{4T}	8.98 (2.31)*	b	58.8 (3.28)*
Commuter Rail Access to Park Land, X_{4C}	51.8 (1.75)	b	363 (3.01)*

* Coefficient significant, absolute t-value greater than 2.00 (two-tail, $\alpha = .05$).

a Coefficients on endogenous variables simultaneously estimated in five equations.

b Coefficients estimated, not included, absolute t-value less than 1.00.

+ Sign same as predicted (3SLs only). Note that only limited predictions were made.

Table 6. Employment Location Equations, 1970, Estimated by Ordinary Least Squares, Regression Coefficients (Absolute t-Values in Parentheses)

Dependent Variables (Persons)	Water Using Air Polluting Manufacturing, E_1	Other Manufacturing, E_2	Non- Manufacturing E_3
Right-Hand Variables			
White Population, R_1	b	0.0643 (3.26)*	0.0981 (5.67)*
Black Population, R_2	0.0133 (2.07)*	b	0.114 (4.14)*
General Access to White Population R_{1G}	b	0.511 (5.63)*	b
Rail Transit Access to White Population, R_{1T} ($\div 10^3$)	-0.0648 (-3.91)*	0.349 (4.30)*	1.12 (15.71)*
Rail Transit Access to Black Population, R_{2T} ($\div 10^3$)	-0.940 (-3.54)*	-1.36 (-1.04)	-2.95 (-2.59)*
Commuter Rail Access to White Population, R_{1C} ($\div 10^3$)	-2.58 (-2.50)*	b	-8.12 (-1.83)
Commuter Rail Access to Black Population, R_{2C} ($\div 10^3$)	52.3 (5.46)*	b	b
Water Flow Index, X_1	0.291 (2.92)*	0.635 (1.31)	b
Channel Capacity Index, X_2	19.2 (19.18)*	5.94 (1.22)	b
Ave. Air Passengers in Prior Decade, X_3 ($\div 10^3$)	b	5.11 (4.50)*	2.04 (2.05)*
General Access to Park Land, X_{4G}	b	-9070 (-3.22)*	2680 (1.08)
Rail Transit Access to Park Land, X_{4T}	9.14 (2.73)*	b	50.5 (3.51)*
Commuter Rail Access to Park Land, X_{4C}	52.3 (1.77)	b	348 (2.76)*
OLS R^2	0.92	0.92	0.99†

NOTE: See notes to Table 1.

† See Footnote No. 7.

Table 7. Resident Location Equations, 1970, Regression Coefficients (Absolute t-Values in Parentheses)

Dependent Variables (Persons)	Three-Stage Least Squares ^a		Ordinary Least Squares	
	White Population, R_1	Black Population, R_2	White Population, R_1	Black Population, R_2
Water Using, Air Polluting Employment, E_1	2.79 (2.15)*	2.24 (2.63)*+	2.05 (1.64)	2.31 (2.78)*
Other Manufacturing Employment, E_2	b	-1.06 (-2.24)*	1.75 (3.14)*	-0.391 (1.06)
Nonmanufacturing Employment, E_3	-0.305 (-1.46)	b	-0.580 (-3.33)*	b
General Access to Water Using, Air Polluting Employment, $\bar{E}_{1G}$ ($\times 10^3$)	39.8 (2.18)* +	-25.9 (-2.16)*	37.3 (1.93)	-30.8 (-2.41)*
General Access to Other Manufacturing Employment, $\bar{E}_{2G}$ ($\times 10^3$)	16.1 (4.75)* +	10.0 (4.49)* +	11.8 (3.49)*	7.78 (3.47)*
General Access to Non-Manufacturing Employment, $\bar{E}_{3G}$ ($\times 10^3$)	-8.52 (-4.76)*	-3.93 (-3.34)*	-7.00 (-3.84)*	-3.17 (-2.67)*
Rail Transit Access to Water Using, Air Polluting Employment, $\bar{E}_{1T}$ ($\times 10^3$)	852 (1.48)	1480 (3.90)* +	858 (1.40)	1405 (3.46)*
Rail Transit Access to Non-Manufacturing Employment, $\bar{E}_{3T}$ ($\times 10^3$)	8.89 (3.43)* +	b	9.01 (3.33)*	b
Commuter Rail Access to Water Using, Air Polluting Employment, $\bar{E}_{1C}$ ($\times 10^3$)	-6.18 (-1.44)	b	b	b
Commuter Rail Access to Non-Manufacturing Employment, $\bar{E}_{3C}$ ($\times 10^3$)	45.3 (3.16)* +	b	39.0 (2.64)*	b
Land Area Devoted to Public Parks, X_4	4840 (2.92)* +	b	5190 (2.93)*	b
Rail Transit Access to Water Flow, $\bar{X}_{1T}$	b	-3.07 (2.75)*	b	-2.54 (-2.12)*
Rail Transit Access to Channel Capacity, $\bar{X}_{2T}$	-17.5 (-2.22)*	5.35 (1.03)	-18.5 (-2.27)*	5.62 (1.04)
General Access to Airport Activity, $\bar{X}_{3G}$ ($\times 10^3$)	b	-146 (-2.94)*	b	-111 (-2.09)*
OLS R^2			.64	.68

*Coefficient significant, absolute t-value greater than 2.00 (two-tail, $\alpha = .05$).^aCoefficients on endogenous variables simultaneously estimated in five equations.^bCoefficient estimated, not included, absolute t-value less than 1.00.⁺Sign same as predicted (3SLS only). Note that only limited predictions were made.

probably also the case for simultaneous estimation as well. An effort was made in this model to include as many variables as time and methods would allow in order to reduce possible bias. This approach is different from that taken by both Empiric, S-F, and F-F. These works excluded all variables whose coefficient t-value was less than a cut-off value denoting statistical significance. This usually tends to raise coefficient values and estimates of significance but it may also result in undesirably biased coefficient estimates.

One method of evaluating the success of the empirical results obtained here is to compare them to similar results obtained in the previous models on which this work is based. Such a comparison is provided in Table 8. The Washington Empiric, the F-F, and the Argonne model are compared in this table. Each model has residential and employment equations, between twelve and seventeen sample zones per equation, about four exogenous variables per equation, and is estimated initially by ordinary least squares (OLS) and finally by simultaneous methods (2SLS or 3SLS). Based on a comparison of overall OLS R^2 results the Argonne model appears to be superior. However, disaggregating the employment and residential equations reveals that the Argonne model owes its overall R^2 superiority to its substantially better employment equation results in combination with slightly inferior residential equation results. This is largely the result of introducing the interurban transportation variables, X_1 through X_3 and disaggregating accessibility by mode.

A second method of evaluating the success of the model is to perform an internal check on the consistency of predictions with empirical results. In terms of the a priori expectations presented in the previous section the model also does reasonably well. If all of the predictions of signs are regarded as predictions that the variable will also be significant with that sign (with the exception of the predictions of insignificance in the E_1 equation) then the predictions are correct in twenty out of thirty-four cases. If, on the other hand, only the signs are considered then the predicted signs are correct in eighteen of twenty-four cases estimated by 3SLS. The Lowry-like predictions of positive values for accessibility generally hold up. Of the estimated coefficients, twelve of seventeen predicted

TABLE 8. Comparison of Urban Simultaneous
Equations Location Models

Model	Type	No. of Equations	No. of Zones	Type of Estimation	No. of Exogenous Variables	Mean OLS R^2 Value for All Equations	Mean R^2 For Employment Equations	Mean R^2 For Residential Equations
Empiric (Wash., D.C.)	Dynamic	5 Residential 4 Employment	110	2SLS	35	.74	.72	.75
Fisher-Fisher (Chicago)	Static	4 Residential 2 Employment	100	3SLS	27	.70	.63	.74
Santini (Chicago- Gary)	Static	2 Residential 3 Employment	76	2SLS	23	.83	.94	.66

accessibility coefficient signs match the predicted positive signs. On the whole then, the model behaves as expected. A more complete evaluation of the absolute and relative importance of coefficients of variables must be done on an equation by equation basis. In the following sections this evaluation is made. The discussion includes both a comparison of prior hypotheses to results and a development of new hypotheses to explain unpredicted results.

5.1 EMPLOYMENT EQUATIONS

The E_1 employment equation, which may be considered a heavy industry employment location equation, indicates the extreme importance of access to raw materials for this class of employer. In 3SLS estimates at the selected level of significance (5 percent) water flow and channel capacity are both important. This result matches expectations and tends to validate the design and definition of the X_1 and X_2 variables. The predicted lack of significance of population or of accessibility to population does not materialize. However, the results indicate that accessibility to the majority of the urban population, white population, has a negative value for major water using air polluters. This is inconsistent with a hypothesis of a positive value for accessibility to potential workers and is inconsistent with results obtained for the two remaining classes of employment. This equation indicates that a Lowry-like assumption¹⁸ that accessibility does not influence the location of "basic" or heavy industries is clearly better than assuming a positive effect of accessibility to population on such industry. The equation can also lead to a better treatment of such industry since it explicitly identifies some of the nonaccessibility locational constraints affecting these industries.

In the equations for other manufacturing, E_2 , and nonmanufacturing, E_3 , the results are good both in terms of OLS R^2 and interpretability. For these two employment categories, accessibility to white population is clearly a significant positive determinant of employment location. Further, as one might expect, general (auto) accessibility is more important for manufacturing (E_2 represents most of manufacturing employment) than nonmanufacturing, while transit accessibility is more important for nonmanufacturing. In fact, the very high t-values for the transit accessibility to whites variable, $\bar{R}_{1T}$, is a result of the transit system's service to the Loop, where the greatest concentration of both E_2 and E_3 exist.

The airport variable, X_3 , indicates that the construction of a major airport can attract a large number of light industries to an area. The coefficients of the park land accessibility variables $\bar{X}_{4G}$, $\bar{X}_{4T}$, $\bar{X}_{4C}$, reemphasize the fact that general (auto) accessibility is important for light industry. One interpretation of the signs found on these variables' coefficients is that those persons with nonmanufacturing skills are likely to ride public rail transportation between the Loop and zones where taxes support public parks, while persons with manufacturing skills are unlikely to commute by automobile from a zone of residence in which they are compelled to pay for public parks. If this interpretation is correct, then it is an example of white collar and blue collar residents sorting themselves in space according to different preferences for public goods, as suggested by Tiebout³⁵.

The one anomolous result found in this set of equations is the combination of a negative and positive coefficient for the black population variables, R_2 and $\bar{R}_{2T}$ in the nonmanufacturing employment, E_3 , equation. A positive coefficient was expected in both cases. Note that the only significant relationship between population and employment in the 3SLS estimates is for R_2 on E_3 , in spite of the fact that four of the six estimated relationships appear significant by OLS. In fact, there is one case (R_1 on E_2) in which the sign changes from OLS to 3SLS in spite of the fact that the coefficient is significant by OLS.

5.2 RESIDENT EQUATIONS

The prediction that blacks would be positively associated with water-using air polluting employment, E_1 , is born out by the R_2 equation results. Two of the three significant E_1 variables in this equation are positive. Somewhat surprising is the result that the two significant E_1 variable coefficients in the R_1 equation are also positive. In fact, the general results of the simultaneous estimates of E on R indicate that water-using air polluting employment is the only class of employment definitely causing population growth within a zone. Further, the relatively high coefficients of the E_1 variables relative to those of the E_2 and E_3 variables indicates a much more substantial impact of shifts in E_1 location than for E_2 or E_3 .

In simultaneous coefficients of the black population equation, the positive effect of E_1 in association with the negative effect of other manufacturing employment, E_2 , may reflect relative employment opportunities in

these categories. It may also indicate an income effect in which lower income blacks are forced by economic necessity to live in environmentally less desirable locations near air polluters.

The negative but insignificant relationship between nonmanufacturing employment and white population reflects the extreme concentration of non-manufacturing employment in the Loop with a consequent absence of residential demand at the high central area land prices. This has been confirmed by estimating a model with the Loop removed from the data. Such a model shows a positive relationship between E_3 and R_1 for all remaining zones.

Significant E_2 and E_3 accessibility coefficients in the population equations again indicate that auto accessibility is important for residents employed in light industry (E_2) and that public rail accessibility is relatively important for residents employed in nonmanufacturing. Positive and significant coefficients for accessibility to light industry are found only in the case of general accessibility. Positive and significant coefficients for accessibility to nonmanufacturing are found only for rail transit and commuter rail.

A reasonable interpretation may be given to each of the four significant market shifter based variables. The positive coefficient for the park area variable, X_4 , in the white population equation agrees with expectations. The coefficients of the rail transit access variables are best understood if one remembers that these variables represent the value of accessibility to zones with a particular attribute. The general effect of a job opportunity in the water using air polluting employment class is already accounted for by the presence of E_1 variables in the R equations. Since water flow and channel capacity are variables important only to the E_1 class of employment their effect must be due to some intraclass variability in employment opportunities to blacks and/or whites. Our familiarity with the data allows us to note that high values of water flow are associated with petroleum refining while high values of channel depth are associated with steel production. In the Chicago SMSA blacks are employed at a lower than average (all manufacturing average) rate in petroleum refining.⁴⁷ Thus a negative coefficient on the access to petroleum refining proxy (rail transit access to water flow) is reasonable in the black population equation. Similarly, in the Chicago SMSA whites are employed at a lower than average rate in steel manufacturing.⁴⁷ Therefore a negative coefficient on the

access to steel manufacturing proxy (rail transit access to channel depth) is logical in the white population equation. Finally, the negative relationship between access to airport activity and black population is also reasonable since blacks are employed at a lower than average rate in air transportation in the Chicago SMSA⁴⁷ and since low income blacks seldom use airport facilities.

6. SUMMARY AND CONCLUSIONS

We have estimated an adapted Steinnes-Fisher econometric model explaining the simultaneous allocation of employment and residence. Our results indicate that the addition of variables measuring water and air transportation opportunities can considerably improve estimates of employment locations and levels in spatial models, econometric or otherwise. The residence equations also show that accessibility variables constructed from air and water transportation measures can contribute significantly to the determination of residential location.

Results of our disaggregation of a class of major water-using air polluters demonstrate first that access to raw materials is more important than access to labor for this class of industry and, second, that this class of employment exerts relatively greater influence on residential location than do other employers. In a general way these two points are consistent with a Lowry type of model of urban location in which our water-using air polluting class of industry is analogous to Lowry's "basic" class of industry.

With respect to work trip mode of transportation, our estimates support the obvious expectations for a city with rail transportation services supporting the central business district (CBD). Rail transportation is most important for CBD dominated nonmanufacturing employee work trips while automobile trips are most common for manufacturing employees.

Finally, the coefficient estimates of our model illustrate that job opportunities have a great deal to do with the spatial distribution of blacks and whites.

7. COMMENTS ON FURTHER RESEARCH

Although the results presented here appear to be reasonably good, they should not be over-interpreted. For example, employment is not well correlated with emissions. Fossil fuel power plants have hundreds of employees while steel mills have thousands. Power plants, however, usually have greater potential emissions than steel mills. Even this does not indicate the complexity of the problem. Steel mill emissions sources such as blast furnaces create emissions at a much lower level than do tall stacks of power plants. As a result, local pollutant concentrations from steel mills can be more severe than from power plants. To compound these difficulties, meteorological conditions must be considered in estimating pollutant concentrations.

The research presented here makes the point that waterways are important to a broad class of air polluting industries. It appears to be a point worth making, since prior research and planning appears to often neglect this fact. However, a good understanding of industrial location really requires an industry by industry analysis. This appears to be the only way to understand the location decisions of non-water using air polluting industry. Some work in this area has been conducted by Campbell and Santini³ but substantial work remains to be done. The work by Campbell and Santini indicates that, although non-water using air polluters are relatively more dispersed than water users, there are strong forces tending to cause clustering of these industries as well. This can be readily understood by comparing the concentrations of all major air polluters in Fig. 10 to those of water users in Fig. 6. Many of the non-water users are found in close proximity to water users. This arises because of strong input-output linkages between the two types of air polluting industry. The degree of these linkages in the Chicago area can be seen in Fig. 11.

While the general pattern of non-water using air polluting employment is clearly influenced strongly by input-output linkages, this knowledge does not provide one with as powerful measures of non-water user location as do waterway attributes for water users. Locations where waterways can economically be constructed are very limited, usually by existing natural channels.

FIG. 10 CONCENTRATIONS OF MAJOR AIR POLLUTING INDUSTRIAL EMPLOYMENT

Fig. 11. Input-Output Linkages Among Chicago Area Air Polluting Industrial Groups (Other Linkages Exist Over a Larger Region)

However, rail or truck input-output opportunities are much more ubiquitous than water transport linkages. Since many of the non-water users ship by truck or rail, their locational options are much less restricted, even though they may choose to be in the vicinity of their suppliers and customers. The upshot is that, although regressions were tested for nonwater users, they were not nearly as successful as those presented for water users. Since non-water users have only about half of the employment of water users, it would have been possible to present a seemingly good equation for all air polluters. This would have glossed over the fact that a determination of the locational decisions of non-water users requires detailed analysis on an industry-by-industry basis.

Input-output linkages are one aspect of the locational characteristics of major air polluters that we have only begun to examine. The theoretical structure followed in the location model does not even allow for the existence of such linkages. The addition of such considerations would have greatly complicated the modeling effort and would have removed it one step further from prior spatial modeling work. It does seem that the explicit theoretical addition of such considerations as input-output linkages, shopping trips, and social trips to an econometric location model is a logical next step.

A complete urban location and air pollution model must consider trips in great detail since automobile and truck emissions contribute as much to poor urban air quality as industrial emissions. Whether this can be done productively with the class of models examined in this report is an open question. We had anticipated an attempt to examine this problem with econometric methods if the spatial modeling effort had continued. Data on vehicle miles travelled and average speed by location has been provided to Argonne by the Chicago Area Transportation Study but no compilation of this data has been done.

It should be mentioned that the modeling work done here could very easily be shifted to an energy modeling effort. Since air pollution is caused primarily by combustion or evaporation of products derived from fossil fuels, there is a great deal of natural overlap between generation of air pollution and consumption of energy. The Chicago area is also a good area to

study in this regard since it includes major national air polluting energy consuming industry as well as all of the urban public transportation alternatives to the automobile. Only the New York region includes as many useful opportunities for study in the U.S.

APPENDIX A - THE DATA SET

Our complete spatial model data set includes the values of over 60 variables for each of the 76 spatial model zones. Two types of variables are included in the data set. First, there are variables copied or calculated from basic sources, which may be called data variables. Secondly, there are variables derived from the data variables, which may be called derived variables. An example of a data variable might be the population of a zone or employment in the zone. An example of a derived variable might be a transportation accessibility variable.

This appendix is divided into four parts. The first part describes the data variables in the data set. The second part describes the method of derivation. The third, since not all variables in the data set are actually used in the spatial model, presents a separate listing of the variables used in the model and their relation to the variables in the data set. Fourth, we present the data set itself.

A.1 THE DATA VARIABLES

The spatial model data set includes the following classes of data variables:

- employment variables,
- land use variables,
- population variables,
- variables relating to the waterway system, and
- a variable relating to air transportation.

Each of these classes of data variables will be discussed in a separate section below.

First, however, a couple of general remarks are in order. Some of the data described in the sections to follow was simply copied from publications we used. In other cases, particularly in the City of Chicago, considerable aggregation was necessary in order to obtain variable values for our spatial model zones. Depending on the degree of aggregation necessary, and the form in which the data was available to us, it was sometimes more convenient to aggregate the data by hand, and sometimes by computer. It is

not usually pointed out in the following sections whether the data was aggregated by hand, by computer, or by some combination of the two, since the same result is obtained by either method. The algebraic procedure used in aggregating the data is, however, always presented so that anyone who desires may duplicate our work.

Another general remark concerns consistency checks. At many points in compiling the data, consistency checks were carried out to test the accuracy of our own calculations. Consistency checks of this type are not described in the appendix. Consistency checks were also carried out to test the degree of correspondence between different data sources. Consistency checks of this latter type usually are described in the appendix.

A.1.1 Employment Data

Our data set includes employment by place of work for each of the nine employment categories listed in Table A.1.

Table A.1. Suburban Factbook Employment Categories

Computer Name of Variable	Description of Employment Category	SIC Codes
CMQEMP	Mining, Quarrying & Contract Construction	10-17
TCUEMP	Transportation, Communication & Utilities	40-49
MFGEMP	Manufacturing	19-39
WRTEMP	Wholesale and Retail Trade	50-59
SRVEMP	Services, Finance, Insurance & Real Estate	60-89
GVTEMP	Government	91-93
AGSEMP	Agriculture and Self-Employed	
POLEMP	Manufacturers which are Major Air Polluters	
WUPEMP	Manufacturers which are Major Air Polluters and Major Water Users	

The last two categories will be explained in more detail later on. First, the sources of data for the first seven employment variables listed above will be discussed.

Our data for most of suburban Northeastern Illinois comes from Table 12 of the Suburban Factbook,²¹ which lists employment data by townships. The correspondence between the columns of Table 12 and the first seven employment variables in our data set is exact.

Our data for the City of Chicago and some of the adjacent suburban townships comes from a Northeastern Illinois Planning Commission (NIPC) computer tape listing sixteen categories of employment by quarter square mile.²³ In addition to the obvious spatial aggregation, it was necessary to aggregate some of the employment categories on the NIPC tape in order to obtain the employment variables in our data set. The correspondence between the employment variables in our data set and the employment categories in the NIPC tape is listed in Table A.2.

Table A.2. NIPC Tape Employment Correspondences

Computer Name	NIPC Tape Employment Category	Column*
CMQEMP	Mining & Quarrying	2
	Contract Construction	3
TCUEMP	Transportation & Warehousing	6
	Communications & Public Utilities	7
MFGEMP	Durable Goods Manufacturing	4
	Nondurable Goods Manufacturing	5
WRTEMP	Wholesale Trade	8
	Retail Trade	9
SRVEMP	Finance, Insurance & Real Estate	10
	Services & Miscellaneous	11
	Institutions	12
GVTEMP	Federal Government	13
	State Government	14
	Local Government	15
AGSEMP	Farms & Forestry	1
	Self-Employed, Unpaid Family	
	Workers & Domestic Workers	16

*The numbers listed in this column represent the order in which the employment categories are listed on the NIPC tape.

Employment values for several suburban townships were calculated using the quarter square mile data from the NIPC tape, and found to be quite consistent for the most part with Table 12 of the Suburban Factbook. Employment values for the City of Chicago calculated using the quarter square mile data were, however, between about 5 and 20% higher than those listed in the Suburban Factbook. The discrepancy was least for manufacturing employment, and greatest for services employment.

Some inadequacies were present in the quarter square mile data for manufacturing employment. In particular, small or even zero values were listed for manufacturing employment in locations where firms with large employments were known to exist, perhaps because employment at a manufacturing plant was sometimes erroneously assigned to a downtown business office. (This was particularly true of steel mills in South Chicago.) We corrected for this as follows. First, we checked all manufacturers with more than 1000 employees to see if any of them were conspicuously left out of the quarter square mile data, and revised the quarter square mile data wherever this was the case. We then computed the final revised manufacturing employment data with the help of the publication Where Workers Work,¹² in which employment data for the City of Chicago is listed by postal zone. This was done by assigning manufacturing employment for a postal zone to the spatial model zone containing it. Where a postal zone was divided between more than one spatial model zone, its manufacturing employment was assigned to the spatial model zones containing it in proportion to the manufacturing employment listed in the overlapping regions by the quarter square mile data.

A hypothetical example is given below.

Suppose Where Workers Work lists the following manufacturing employment figures:

60001	2000
60002	3000
60003	4200

and the quarter square mile data lists the following manufacturing employment figures:

I	2000
II	800
III	1600
IV	4000

Before revision, zones A and B are assigned manufacturing employment of 2800 and 5600, respectively. After revision, they are assigned manufacturing employments of 3000 (2000 + 1000) and 6200 (2000 + 4200), respectively.

Our basic source of data for the Northwestern Indiana region was Table 7 of the Employment Survey Technical Report²⁷ which lists employment data by townships. The correspondence between the employment variables in our data set and the columns of Table 7 of the NIRPC report is listed in Table A.3.

Table A.3. NIRPC Data Employment Correspondences

Computer Name	NIRPC Report Employment Category	Column*
CMQEMP	Construction	LC
TCUEMP	Transportation, Communication & Utilities	LN
MFGEMP		LD to LM
WRTEMP	Trade	LO
SRVEMP	Finance, Insurance & Real Estate	LP
	Service	LB
GVTEMP	Government	LR
AGSEMP	Other	UN

*The letters listed in this column are those used as column headings in Table 7 of the NIRPC Report.

The correspondence above is not exact, but reference to County Business Patterns, 1970: Indiana⁴⁴ reveals that the employment categories for which the correspondence fails are insignificant in Northwestern Indiana anyway.

The first seven employment categories have now been discussed. It remains to discuss the last two.

There are two versions of the polluting employment variable (POLEMP) in our data set, and two corresponding versions of the water using polluting employment variable (WUPEMP). The first version of polluting employment was derived from the Illinois EPA Uncontrolled Emissions Inventory for 1973.¹⁴ Those manufacturers whose uncontrolled emissions exceeded 100 pounds per hour of any one of the five major air pollutants were classified as major air polluters. The second version of polluting employment was derived from the

Illinois EPA Controlled Emissions Inventory for 1974. Those manufacturers whose controlled emissions exceeded 1000 tons per year for any of the five major air pollutants were classified as major air polluters. In either case, polluting employment was calculated as employment in firms classified as major air polluters. Locations for the firms in question were found from EPA lists,¹⁴ the Illinois Manufacturer's Directory,¹⁹ and telephone books. Our basic source of employment data for air polluting firms was the 1970 Illinois Manufacturer's Directory. This source was in many cases supplemented by other sources, in order to check its accuracy, and fill in missing data. In occasional cases, phone calls were resorted to for locations and/or employment figures.

In Northwestern Indiana, we did not have access to an air pollution inventory similar to those used in Illinois. Instead, we relied on information sent to us by the Northwestern Indiana Regional Planning Commission, which listed location and employment for the sixteen largest firms in Northwestern Indiana. Educated guesses based on the Illinois inventory were used to determine which firms should be classified as air polluters, and polluting employment was calculated as employment in these firms plus power plant employment in the same zones (from Refs. 27 and 44). This procedure is acceptable for the following two reasons. First, educated guesses as to which firms are major air polluters are more reliable for the types of firms represented in Northwestern Indiana (e.g. primarily steel mills and refineries) than they would be on the average in Northeastern Illinois. Second, giving consideration only to the sixteen largest firms is adequate for an employment location model, since manufacturing employment in Northwestern Indiana is dominated by these sixteen firms. (They account for about 80% of the total.)

Water using polluting employment (WUPEMP) was derived from polluting employment (POLEMP) as follows. The Census of Manufacturers⁴⁵ was used to define an industry as a water-user if the national average water intake per firm in the four digit standard industrial class is more than 10^9 gallons per year. Water-using polluting employment was calculated as employment in air polluting firms belonging to water-using industries.

A.1.2 Land Use Data

Our data set includes square miles devoted to each of the eight land use categories listed in Table A.4.

Table A.4. Suburban Factbook Land Use Categories

Computer Name of Variable	Description of Land Use Category
RSDREA	Residential
COMREA	Commercial
MFGREA	Industrial
NSTREA	Institutional
PLCREA	Public Open Space
AVTREA	Agriculture/Vacant
TRSREA	Transportation, Communication, Utilities, and Mining
STAREA	Streets

Our data for suburban Northeastern Illinois comes from Table 25 of the Suburban Factbook²¹ which lists land use data by township. The columns of Table 25 correspond exactly to the land use categories in our data set.

Our data for the City of Chicago comes from computer cards sent to us by the Chicago Department of Development and Planning (CDDP),⁶ which lists hundreds of square feet devoted to each of eleven land use categories by quarter square mile. In addition to the obvious spatial aggregation, it was necessary to aggregate some of the land use categories of the CDDP data. The correspondence of CDDP land use categories with those of Table A.4 is presented in Table A.5.

Two points should be noted about the CDDP data. First, some care was necessary in compiling the land use data for those sections of southern Chicago lying along the Indian Boundary Line, where the grid system used has a discontinuity. Correction cards supplied by the CDDP were used in place of or in addition to the originals for the sections concerned, as determined by case-by-case inspection. Secondly, it was necessary to proportionately scale down the data for many of the quarter sections, since in many cases the total land area allotted to the eleven land use categories was slightly greater than one quarter square mile.

Table A.5. CDDP Data Land Use Correspondences

Computer Name	CDDP Land Use Category	Column*
RSDREA	Residential	1
COMREA	Commercial	3
	Office	4
	Parking	9
MFGREA	Manufacturing	2
	Warehousing	5
NSTREA	Public Buildings	6
PLCREA	Public Open Space	7
AVTREA	Vacant	10
TRSREA	Trans/Comm/Util	8
STAREA	Streets	11

*The numbers listed in this column represent the order in which the land use categories are listed in the CDDP data set.

Our data for Northwestern Indiana comes from some information sent to us by the Northwestern Indiana Regional Planning Commission, which lists acres devoted to each of eight land use categories by township.²⁴ The land use categories in this information correspond exactly to the land use categories in our data set.

Land use figures for the whole City of Chicago were calculated using the CDDP quarter square mile data, and found to be in reasonably good agreement with the corresponding values listed in Table 25 of the Suburban Factbook. Agreement was very good for the two largest land use categories, residential and streets, and also for total land area. Agreement was not quite as good for the other categories, with differences of about 10 to 25%.

In addition to the eight land use variables discussed in the last section, total land area (computer name LDAREA) is also included in the data set. It would of course be expected that the sum of the eight land use categories equal the total land area in the zone. This is true for our data set (to within rounding errors) except for a few of the zones in Northeastern Illinois, where total land area exceeds the sum of the eight land use categories by up to 6%.

A.1.3 Population Data

Our data set includes the two population variables listed below.

Computer Name of Variable	Description of Variable
PPTN70	Total 1970 Population
PCTWHT	Percentage of above which is white

White population and black population are easily calculated from the above two variables. (It should be noted that in the spatial model, black population is defined as all non-white population.)

Our data for suburban Northeastern Illinois comes from Tables 13 and 15 of the Suburban Factbook.

Our data for the City of Chicago comes from a Bureau of the Census tape for the Chicago SMSA. The census tape divides population data by sex and nine different racial categories. From this, total population and white population were generated for each census tract. Population for a census tract was assigned to the spatial model zone containing it. Where a census tract was divided between more than one spatial model zone, its population was assigned to the spatial model zones containing it in proportion to the overlapping areas. Total population and white population were thus calculated for each spatial model zone, and from these the percentage of population which is white.

Our data for Northwestern Indiana comes from a table on page 46 of the Extract of General Population and Housing Characteristics.²⁵

Total population and white population for the whole City of Chicago were calculated using the census tape data, and found to be in very good agreement with the corresponding values listed in Tables 13 and 15 of the Suburban Factbook.

A.1.4 Water Variables

Several variables in the data set relate to the Chicago area waterway system. They may be grouped into three classes, relating to water flow, channel depth, and lakeshore. Each class is described in turn below.

Water flow through a zone can induce firms with large water intake requirements to locate in the zone. Two water flow variables are included in the data set, derived as follows. Let the subscript i denote the i^{th} segment of river or canal in the zone. Let L_i denote the length of segment i (in miles) whose banks are devoted to private land use. (Forest preserves, for example, are not included.) Where only one of the two banks is devoted to private land use, or where the waterway flows along the boundary of the zone, the length is only counted as half. Let G_i denote the water flow of the segment (in mgd). The first water flow variable, F_1 , is formed by summing $L_i G_i$ over all the waterway segments in the zone. The second water flow variable, F_2 , is formed by summing $L_i \sqrt{G_i}$ over all the waterway segments in the zone. In the example below, where all waterway banks are assumed devoted to private land use, the first water flow variable takes the value 125, and the second takes the value 29.

One problem is that water flows are not constant over time. Instead of letting G_i represent an average or median flow, we let it equal a low flow value, but not an extreme low flow value. Our values of G_i represent roughly the water flows which are exceeded 80% of the time, although in some cases, our data probably has a significant percentage of error. Our flow data for the sanitary canal - Chicago River system comes from the diagram on page 16 of The Water Resource in Northeastern Illinois.²² (Pages 112-114 of Water Resources Data for Illinois⁴⁹ suggest these values of water flow might

be exceeded roughly 80% of the time.) Flow values for the Fox River are derived from graphs on pages 20-21 of The Water Resource.²² Flow values for the Grand Calumet River and the Indiana Harbor Canal in Northwestern Indiana are figured out (roughly) from information in chapters 2 and 3 of the Snow report.³² All other waterways in the study area have quite insignificant low flow values (see pages 20-21 of Ref. 22, pages 45-55 of Ref. 34, and see Refs. 48 and 49).

Water channels with significant depth can induce firms to locate in a zone because of the convenience of water transportation. Three channel depth variables are included in the data set, derived as follows. Let the subscript i denote the i^{th} segment of river or canal in the zone, where only navigable waterways are included. Let L_i denote the length of segment i (in miles) whose banks are devoted to private land use, with a factor of one half applied when only one bank is devoted to private land use or the waterway flows along the boundary of the zone. Let D_i represent the controlling channel depth of the segment (in feet). The first channel depth variable, $D1$, is formed by summing L_i over all the waterway segments in the zone. (This variable represents the total length of navigable waterways in the zone whose banks are devoted to private land use.) The second channel depth variable, $D3$, is formed by summing $L_i D_i^3$ over all the waterway segments in the zone and dividing by 100. The third channel depth variable, $D5$, is formed by summing $L_i D_i^5$ over all the waterway segments in the zone and dividing by 100,000.

Our channel depth data comes from bulletins, maps, and charts (see Refs. 37, 38, 39 and 40). Waterways included in the formulation of our channel depth variables include the Calumet Sag Channel, the Sanitary and Ship Canal, the Des Plaines River in Joliet, the Chicago River, the Indiana Harbor Canal, and commercial harbors along Lake Michigan. Channel depths used for D_i are controlling channel depths instead of actual channel depths, since it does little good to have a deep channel segment if access to it is limited by adjacent shallower channel segments. In the example below, the whole waterway would be assigned a channel depth of 9 feet.

Some firms might be attracted to locations adjacent to Lake Michigan. Miles of lakefront devoted to private land use, M, and miles of lakefront devoted to public parks, PKLAKE, are the last waterway variables included in the data set. Only lakefront locations whose topography is suited to the location of industry are included in M. Most of the north suburban lakefront is rendered unsuitable for industry by bluffs rising 50 feet or more above lake level. In some parts of Northwestern Indiana, large sand dunes create a problem. Most of the lakeshore in Chicago, otherwise suitable for industry, is devoted to public parks. North and Calumet townships in Northwestern Indiana, however, do have large amounts of privately-owned lakeshore suitable for industry.

Our data for the lakefront variables was derived by inspection of USGS topographical maps. Sections of lakeshore for which the 600 foot contour lines are more than 1/2 mile from Lake Michigan (mean level 580 feet), or where only mild sand dunes are above 600 feet, were classified as suitable for the location of industry, and were included in the M variable.

A.1.5 Airport Activity

An index of airport activity was developed from Civil Aeronautics Board statistics for 1960 and 1970.^{42,43} Either air freight or air passenger enplanements could have been used since the spatial zone measurements of the two correlate with an r^2 greater than 0.99. The variable

selected is an average of Midway or O'Hare air passenger enplanements in 1960 and 1970. Its acronym is AIRPS.

A.2 CONSTRUCTED (ACCESSIBILITY) VARIABLES

Accessibility variables are constructed as follows: $\bar{Y}_{ki}$ = the accessibility value for any variable Y_k , for area k , defined as $\sum_{k' \neq k} Y_{k'} / t_{kk'i}$, where $i = G, T, \text{ or } C$, and where $t_{kk'i}$ = assumed travel cost function from area k to k' for travel mode i , where $i = G, T, \text{ and } C$.

Travel cost functions by mode are defined as:

$t_{kk'G}$ = generalized (highway) travel cost function. At the level of resolution for which this model is designed it is assumed that airline distance, $d_{kk'}$, between zones is an adequate proxy for travel time. See Santini²⁸ and Baxter and Lenzi¹ for a discussion of the adequacy of this assumption. Here $t_{kk'G} = d_{kk'}^2$. A power of one was also tried in early model work, proving to be less satisfactory (from Refs. 21 and 27).

$t_{kk'T}$ = rail rapid transit travel cost. Cost per zone resident is assumed to decrease with the number of stations found in each zone, s_{kT} . A relatively uniform speed and frequency of service is assumed to exist on each of the rapid transit lines, since they are part of a single system. Since people generally take longer trips by rail, (rapid transit or commuter rail) it is assumed that travel costs increase less rapidly with distance on rail than on highway systems. Therefore, the rail transit system distance, $r_{kk'T}$, is raised to a power of one in the travel cost function. Thus $t_{kk'T} = r_{kk'T} / s_{kT} s_{k'T}$ (from Refs. 5, 7, 13).

$t_{kk'C}$ = commuter rail travel cost. There are substantial differences in level of service provided by the commuter railroads. As a consequence, it is desirable to add the frequency of inbound rush hour (7:00-9:00 a.m.) trains, f_C , and the proportion of on time trains, p_C , to the commuter rail travel cost function. $t_{kk'C} = r_{kk'C} / (s_{kC} s_{k'C} f_C p_C)$. The commuter rail travel cost function thus is a rush hour cost function particularly appropriate for the work trip (from Refs. 9 and 31).

The variables constructed in the data base, their acronyms, and their interpretation are as follows:

I. General (Highway) Accessibilities

- a. AWUPL2 = general accessibility to water using air polluting manufacturing employment using a power of two.
 $Y = WUPEMP.$
- b. ANWPL2 = general accessibility to non-water using air polluting manufacturing employment. $Y = POLEMP - WUPEMP.$
- c. AOMFG2 = general accessibility to manufacturing employment of industries who are not major air polluters.
 $Y = CMQEMP + TCUEMP + MFGEMP - POLEMP.$
- d. ASRVS2 = general accessibility to services employment.
 $Y = SRVEMP.$
- e. AOTHR2 = general accessibility to other nonmanufacturing employment. $Y = WRTEMP + GVTEMP + AGSEMP.$
- f. AWHPP2 = general accessibility to white population.
 $Y = PPTN70 * PCTWHT.$
- g. ABLPP2 = general accessibility to black population.
 $Y = PPTN70 * (1.0 - PCTWHT).$
- h. AFLW2 = general accessibility to canal or river water flow. $Y = F1$ (flow index based on flow to the first power).
- i. ADPTH2 = general accessibility to channel depth. $Y = D5$ (depth index based on depth to the fifth power).
- j. AAIRP2 = general accessibility to air passenger emplanements.
 $Y = AIRPS.$
- k. APKRA2 = general accessibility to public park area.
 $Y = PLCREA + PKLAKE.$

II. Rail Rapid Transit Accessibilities

- a. ATSWUP = transit accessibility to water using air polluting employment. $Y = WUPEMP$.
- b. ATSNUP = transit accessibility to non water using air polluting employment. $Y = POLEMP - WUPEMP$.
- c. ATSMFG = transit accessibility to manufacturing employment of industries who are not major air polluters.
Y same as I.c.
- d. ATSSRV = transit accessibility to services employment.
Y = SRVEMP.
- e. ATSOTR = transit accessibility to other nonmanufacturing employment. Y same as I.e.
- f. ATSWHP = transit accessibility to white population.
Y same as I.f.
- g. ATSBLP = transit accessibility to black population.
Y same as I.g.
- h. ATSFLW = transit accessibility to canal or river water flow. $Y = F1$.
- i. ATSDPT = transit accessibility to channel depth.
Y = D5.
- j. ATSAIR = transit accessibility to air passenger emplanements. $Y = AIRPS$.
- k. ATSPRA = transit accessibility to public park area.
Y = PLCREA + PKLAKE.

III. Commuter Rail Accessibilities

- a. ARRWUP = commuter rail accessibility to water using, air polluting employment. $Y = WUPEMP$.
- b. ARRNUP = commuter rail accessibility to non water using air polluting employment. $Y = POLEMP - WUPEMP$.

- c. ARRMFG = commuter rail accessibility to manufacturing employment of industries who are not major air polluters. Y same as I.c.
- d. ARRSRV = commuter rail accessibility to services employment. Y = SRVEMP.
- e. ARROTR = commuter rail accessibility to other nonmanufacturing employment. Y same as I.e.
- f. ARRWHP = commuter rail accessibility to white population. Y same as I.f.
- g. ARRBLP = commuter rail accessibility to black population. Y same as I.g.
- h. ARRFLW = commuter rail accessibility to canal or river water flow. Y = F1.
- i. ARRDPT = commuter rail accessibility to channel depth. Y = D5.
- j. ARRAIR = commuter rail accessibility to air passenger emplanements. Y = AIRPS.
- k. ARRPRP = commuter rail accessibility to public park area. Y = PLCREA + PKLAKE.

A.3 VARIABLES USED IN THE MODEL

Variables used in the model are expressed in the form in which they are presented in the body of the text and are here related to the variables in the data base by the acronyms used in this Appendix, as follows:

- E_1 = WUPEMP
- E_2 = CMQEMP + TCUEMP + MFGEMP - WUPEMP
- E_3 = WRTEMP + GVTEMP + SRVEMP + AGSEMP
- R_1 = PCTWHT * PPTN70
- R_2 = (1.0 - PCTWHT) * PPTN70
- X_1 = F1
- X_2 = D5
- X_3 = AIRPS
- X_4 = PLCREA + PKLAKE

$\bar{E}_{1G}$	=	AWUPL2
$\bar{E}_{1T}$	=	ATSWUP
$\bar{E}_{1C}$	=	ARRWUP
$\bar{E}_{2G}$	=	AOMFG2 + ANWPL2
$\bar{E}_{2T}$	=	ATSMFG + ATSNUP
$\bar{E}_{2C}$	=	ARRMFG + ARRNUP
$\bar{E}_{3G}$	=	ASRVS2 + AOTHR2
$\bar{E}_{3T}$	=	ATSSRV + ATSOTR
$\bar{E}_{3C}$	=	ARRSRV + ARROTR
$\bar{R}_{1G}$	=	AWHPP2
$\bar{R}_{1T}$	=	ATSWHP
$\bar{R}_{1C}$	=	ARRWHP
$\bar{R}_{2G}$	=	ABLPP2
$\bar{R}_{2T}$	=	ATSBLP
$\bar{R}_{2C}$	=	ARRBLP
$\bar{X}_{1G}$	=	AFLOW
$\bar{X}_{1T}$	=	ATSFLW
$\bar{X}_{1C}$	=	ARRFLW
$\bar{X}_{2G}$	=	ADEPTH
$\bar{X}_{2T}$	=	ATSDPT
$\bar{X}_{2C}$	=	ARRDPT
$\bar{X}_{3G}$	=	AAIRP2
$\bar{X}_{3T}$	=	ATSAIR
$\bar{X}_{3C}$	=	ARRAIR
$\bar{X}_{4G}$	=	APLCRA
$\bar{X}_{4T}$	=	ATSPRA
$\bar{X}_{4C}$	=	ARRPRA

A.4 THE DATA BASE

Following pages present all of the data discussed in the previous sections. This includes more detailed data than is actually used in the model presented in this report. All of the data necessary to construct accessibility variables is included in the event later researchers might wish to study different aggregation schemes from those used here. Initial pages present a map and index of zone locations and names. Following pages present data necessary to construct accessibility variables. Finally the data base itself, as used to generate the estimates shown in Tables 5 to 7, is presented.

FIG. A.1 STUDY AREA ZONE LOCATION INDEX MAP
(SEE TABLE A.6)

Table A.6.1. Study Area Zone Locations (See Fig. A.1)

No.	Zone	Coordinates		No.	Zone	Coordinates	
		E-W	N-S			E-W	N-S
	<u>CHICAGO</u>	X	Y		<u>SUBURBAN COOK</u>	X	Y
1	Loop	9.1	4.0	31	Orland	-2.9	-15.3
2	Jefferson Park	2.1	10.6	32	Palatine	-12.9	20.4
3	Rogers Park	6.2	11.0	33	Palos	-2.9	-9.2
4	Belmont-Cragin	2.1	7.6	34	Proviso	-2.9	2.9
5	Lakeview	6.6	7.5	35	Rich	3.2	-21.6
6	Austin	3.9	4.5	36	Schaumburg	-14.6	14.8
7	Near West Side	7.0	4.5	37	Stickney	2.3	-2.5
8	Lawndale	4.7	0.8	38	Thornton	10.0	-15.5
9	Lower West Side	7.0	0.8	39	Wheeling	-7.0	20.4
10	Douglas	9.3	0.5	40	Worth	2.9	-9.2
11	Chicago Lawn	4.6	-3.5		<u>DUPAGE COUNTY</u>		
12	Washington Park	9.0	-2.3	41	Addison	-8.7	9.0
13	Chatham	9.2	-5.5	42	Bloomington	-14.6	9.2
14	Roseland	8.0	-8.2	43	Downers Grove	-9.0	-4.4
15	Riverdale	9.5	-10.5	44	Lisle	-15.1	-3.2
16	South Chicago	13.2	-8.5	45	Milton	-14.6	3.2
	<u>SUBURBAN COOK</u>			46	Naperville	-20.9	-2.9
17	Barrington	-18.9	20.6	47	Wayne	-20.4	9.0
18	Brwn-Ccro-OkPk	1.3	2.5	48	Winfield	-20.6	2.9
19	Bloom	10.0	-21.6	49	York	-9.0	3.0
20	Bremen	2.9	-15.3		<u>KANE CO.</u>		
21	Elk Grove	-8.7	14.8	50	Aurora	-27.0	-3.2
22	Evanston	6.0	15.2	51	Dundee	-25.0	20.9
23	Hanover	-20.4	14.8	52	Elgin	-26.5	14.8
24	Lemont	-8.5	-10.4	53	Geneva-Batavia	-26.7	2.9
25	Leyden	-4.9	11.0	54	St. Charles	-26.5	9.2
26	Lyons	-2.9	-3.2				
27	Maine	-2.7	14.6				
28	New Trier	3.4	18.9				
29	Niles	2.7	14.6				
30	Northfield	-1.0	19.9				

Table A.6.2. Study Area Zone Locations
(See Fig. A.1)

No.	Zone	Coordinates	
		E-W	N-S
	<u>LAKE COUNTY, ILL.</u>	X	Y
55	Cuba	-17.7	26.5
56	Deerfield-Wdrfd	-1.0	25.7
57	Ela	-12.6	26.5
58	Libertyville	-6.6	32.3
59	Shields	-1.9	31.8
60	Vernon	-6.8	26.0
61	Waukegan	-1.7	38.6
	<u>WILL COUNTY</u>		
62	DuPage	-15.1	-9.2
63	Frankfort	-3.2	-21.4
64	Joliet	-15.1	-21.4
65	Lockport	-15.1	-15.3
66	New Lenox	-9.0	-21.4
67	Plainfield	-21.1	-15.3
68	Homer	-9.0	-15.3
69	Wheatland	-20.9	-9.2
	<u>LAKE COUNTY, IND.</u>		
70	Calumet	24.0	-17.0
71	Center	23.2	-30.0
72	Hobart	29.0	-19.5
73	North	17.5	-16.0
74	Ross	26.0	-24.2
75	St. John	18.5	-24.0
	<u>PORTER COUNTY, IND.</u>		
76	Prtge-Wstchstr	35.0	-16.0

Table A.7.1. Chicago Transit Authority Rail Rapid Transit Statistics

Zone	Stops	Interzone Distances							
	Number of Stops A=1; B=1; AB=2	Lawndale	Lower West Side	Douglas	Proviso	Brwn-Ccro-OkPk	Austin	West Town	Loop
Washington Park	19	12.5	10.0	3.0	18.2	14.7	11.7	8.5	6.5
Lawndale	5	-	2.5	9.5	13.7	10.2	7.2	4.0	6.0
Lower West Side	3	2.5	-	7.0	11.2	7.7	4.7	1.5	3.5
Douglas	6	9.5	7.0	-	15.2	11.7	8.7	5.2	3.5
Proviso	2	13.7	11.2	15.2	-	3.5	6.5	9.7	11.7
Brwn-Ccro-OkPk	14	10.2	7.7	11.7	3.5	-	3.0	6.2	8.2
Austin	18	7.2	4.7	8.7	6.5	3.0	-	3.2	5.2
West Town	14	4.0	1.5	5.2	9.7	6.2	3.2	-	2.0
Loop	54	6.0	3.5	3.5	11.7	8.2	5.2	2.0	-
Belmont Cragin	1	15.1	12.6	12.6	20.8	17.3	14.3	11.1	9.1
Lakeview	21	10.1	7.6	7.6	15.8	12.3	9.3	6.1	4.1
Jefferson Park	3	15.9	13.4	13.4	21.6	18.1	15.1	11.9	9.9
Rogers Park	27	13.9	11.4	11.4	19.6	16.1	13.1	9.9	7.9
Niles	2	22.1	19.6	19.6	27.8	24.3	21.3	18.1	16.1
Evanston	16	18.1	15.6	15.6	23.8	20.3	17.3	14.1	12.1
New Trier	2	23.5	21.0	21.0	29.2	25.7	22.7	19.5	17.5

Table A.7.2. Chicago Transit Authority Rail Rapid Transit Statistics

Zone	Stops	Interzone Distances						
	Number of Stops A=1; B=1; AB=2	Belmont Cragin	Lakeview	Jefferson Park	Rogers Park	Niles	Evanston	New Trier
Washington Park	19	15.6	10.6	16.4	14.4	22.6	18.6	24.0
Lawndale	5	15.1	10.1	15.9	13.9	22.1	18.1	23.5
Lower West Side	3	12.6	7.6	13.4	11.4	19.6	15.6	21.0
Douglas	6	12.6	7.6	13.4	11.4	19.6	15.6	21.0
Proviso	2	20.8	15.8	21.6	19.6	27.8	23.8	29.2
Brwn-Ccro-OkPk	14	17.3	12.3	18.1	16.1	24.3	20.3	25.7
Austin	18	14.3	9.3	15.1	13.1	21.3	17.3	22.7
West Town	14	11.1	6.1	11.9	9.9	18.1	14.1	19.5
Loop	54	9.1	4.1	9.9	7.9	16.1	12.1	17.5
Belmont Cragin	1	-	5.0	3.0	15.0	23.2	19.2	24.6
Lakeview	21	5.0	-	5.8	3.8	12.0	8.0	13.4
Jefferson Park	3	3.0	5.8	-	9.6	17.8	13.8	19.2
Rogers Park	27	15.0	3.8	9.6	-	8.2	4.2	9.6
Niles	2	23.2	12.0	17.8	8.2	-	4.0	9.4
Evanston	16	19.2	8.0	13.8	4.2	4.0	-	5.4
New Trier	2	24.6	13.4	19.2	9.6	9.4	5.4	-

Table A.8. Illinois Central Gulf Commuter Rail Line Statistics

Zone	Station	Interzone Distances									
	Number of Stations	Douglas	Washington Park	Chatham	Roseland	Riverdale #1	Riverdale #2	South Chicago	Thornton	Bloom	Rich
Loop	4.5	3.0	6.2	9.2	13.1	16.1	15.6	13.2	17.1	21.1	24.1
Douglas	4	-	3.2	6.2	10.1	13.1	12.6	10.2	14.1	18.1	21.1
Washington Pk.	6.5	3.2	-	3.0	6.9	9.9	9.4	7.0	10.9	14.9	17.9
Chatham	6	6.2	3.0	-	3.9	6.9	6.4	4.0	7.9	11.9	14.9
Roseland	7	10.1	6.9	3.9	-	3.0	2.5	7.9	4.0	8.0	11.0
Riverdale #1	6	13.1	9.9	6.9	3.0	-	-	10.9	7.0	11.0	14.0
Riverdale #2	1	12.6	9.4	6.4	2.5	-	-	10.4	6.5	10.5	13.5
South Chicago	6	10.2	7.0	4.0	7.9	10.9	10.4	-	14.9	18.9	21.9
Thornton	5	14.1	10.9	7.9	4.0	7.0	6.5	14.9	-	4.0	17.9
Bloom	1	18.1	14.9	11.9	8.0	11.0	10.5	18.9	4.0	-	3.0
Rich	5	21.1	17.9	14.9	11.0	14.0	13.5	21.9	17.9	3.0	-

Table A.9.1. Commuter Rail Line Statistics

<u>Commuter Railroad</u> (On Time Rating)				<u>Commuter Railroad</u> (On Time Rating)			
Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone	Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone
<u>NORFOLK AND WESTERN</u> (0.80)				<u>ROCK ISLAND (BLUE ISLAND)</u> (0.70)			
Loop	1	1		Loop	1	16	
Douglas	1	1	10	Washington Pk.	1	12	13
Washington Pk.	1	1	5	Chatham	1	2	7
Chicago Lawn	1	1	5	Roseland	1	2	12
Worth	3	1	10	Riverdale	1	16	8
Palos	1	1	10				
Orland	1	1	10	<u>ROCK ISLAND (SUBURBAN)</u> (0.70)			
<u>PENN CENTRAL</u> (0.75)				Loop	1	16	
Loop	1	2		Bremen	2	3	44
Washington Pk.	1	2	15	Frankfort	1	3	11
So. Chicago	1	1	12	New Lenox	1	3	7
North	4	1.5	9	Joliet	1	4	10
Calumet	3	2	12				
Hobart	1	2	10	<u>SOUTH SHORE</u> (0.85)			
				Loop	3	4	
				Washington Pk.	2	3.5	14
				Riverdale	1	4	10
				So. Chicago	1	3	8
				North	2	3	7
				Calumet	2	4	18
				Portage	4	4	19

Table A.9.2. Commuter Rail Line Statistics

<u>Commuter Railroad (On Time Rating)</u>				<u>Commuter Railroad (On Time Rating)</u>			
Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone	Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone
<u>CHICAGO AND NORTHWESTERN (MILWAUKEE LINE)</u> (0.90)				<u>MILWAUKEE ROAD (ELGIN LINE)</u> (0.90)			
Loop	1	10		Loop	1	8	
Lakeview	1	10	9	Austin	1	8	12
Rogers Park	2	4	9	Belmont-Cragin	6	4	11
Evanston	3	7	6	Leyden	5	6	11
New Trier	7	5	11	Addison	2	6	9
Deerfield	5	5	17	Bloomington	2	5	8
Shields	3.5	4	11	Wayne	0.5	5	8
Waukegan	1.5	6	10	Hanover	1.5	6	1
				Elgin	2	7	8
<u>CHICAGO AND NORTHWESTERN (WISCONSIN LINE)</u> (0.90)				<u>MILWAUKEE ROAD (WISCONSIN LINE)</u> (0.90)			
Loop	1	10		Loop	1	8	
Lakeview	1	10	9	Austin	1	8	11
Belmont-Cragin	0.5	4	6	Belmont-Cragin	2	6	7
Jefferson Park	2.5	4	5	Jefferson Park	2.5	5	8
Maine	3	7	5	Niles	2.5	6	8
Elk Grove	1	6	5	Northfield	3	5	10
Wheeling	2	6	4	Deerfield	2	5	9
Palatine	2	5	5	Libertyville	2	3	12
Barrington	0.5	4	6				
Cuba	0.5	4	0				

Table A.9.3. Commuter Rail Line Statistics

<u>Commuter Railroad (On Time Rating)</u>				<u>Commuter Railroad (On Time Rating)</u>			
Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone	Zone	Stations	Inbound Rush Frequency	Minutes to Previous Zone
<u>BURLINGTON NORTHERN (0.90)</u>				<u>CHICAGO AND NORTHWESTERN (GALENA DIVISION) (0.90)</u>			
Loop	1.0	8		Loop	1	11	
Lower West Side	0.5	8	5	Brwn-Ccro-OkPk	1	5	20
Lawndale	0.5	8	5	Proviso	5	3	7
Brwn-Ccro-OkPk	0.5	8	7	York	3	7	8
Proviso	3.0	5	5	Milton	3	6	10
Lyons	4.5	6	6	Winfield	2	7	10
Downers Grove	7.5	7	7	Geneva-Batavia	1	4	5
Lisle	2.0	8	10				
Naperville	1.5	4	10	<u>GULF, MOBILE AND OHIO (0.90)</u>			
Aurora	1.0	11	10	Loop	1	1	
<u>NEW YORK CENTRAL (0.70)</u>				Stickney	1	1	20
Loop	1	3		Lyons	2	1	15
Washington Pk.	1	2	15	Lemont	1	1	10
So. Chicago	2	2	17	Lockport	1	1	10
North	3	1.5	11	Joliet	1	1	10
Calumet	1	3	13				
Westchester	2	1.5	15				

Table A.10.1

E M P L O Y M E N T D A T A									
ZONE	CMWEMP	MEGEMP	SRVEMP	AGSEMP	TOEEMP	WRTEMP	GVTEMP	POLEMP	WIPEMP
LOOP	18680	96264	95731	1681953	96781	134508	55856	0	0
JEFFERSON PARK	3817	241	16152	11733	9290	6516	3266	0	0
ROGERS PARK	5778	615	16364	26068	32668	9248	7064	106	0
BELMONT CRAGIN	3094	400	49630	16952	8212	3071	5175	4310	0
LAKEVIEW	6167	2102	60289	26248	24101	7008	9163	60	0
ASTON	5674	2620	51592	25278	13584	7566	8044	0	0
WEST TOWN	5557	6082	37594	21635	33689	20450	7846	177	0
DOWNDALE	825	7000	34429	15577	6688	7077	5792	518	268
LOWER WEST SIDE	1993	8009	25118	12785	5439	5851	3759	431	281
DOLLAHUS	829	1550	17828	8249	15399	4251	3531	400	0
CHICAGO LAWN	1238	6312	19282	16183	5728	3427	2728	200	50
WASHINGTON PARK	1612	3701	9992	14973	27652	10824	5696	25	0
CHATHAM	3177	1347	13145	11035	9247	8298	3846	0	0
ROSELAND	2512	701	9385	6571	4258	3001	2688	1500	0
RIVERDALE	594	2444	9359	6310	3242	1595	1698	2184	1824
SOUTH CHICAGO	1163	1755	29461	6421	2328	1671	1918	24605	20300
FARRINGTON			600	100	100	200	300	0	
BROWN-CORDELL PARK	2100	4900	31000	15300	10000	5700	4600	1160	
BLOOM	800	1100	16000	6100	2400	2400	2000	4955	220
BREMEN	300	300	1400	2600	3500	2800	700	0	
E K GRIFF	2100	5000	12600	10300	2300	2100	2800	200	
EASTON	1100	1100	6000	10000	23800	2800	3800	60	
HANDLER	200	200	1200	1200	300	900	400	0	
LEMON	100	100	200	400	200	200	100		
LEYDEN	3093	15460	48417	22838	12391	5638	7082	60	0
LIONS	1900	3500	25300	6800	3900	2700	3500	11316	3200
MAINE	3660	1412	13645	16668	11072	4761	4394	35	0
NEW TRIER	500	100	1400	3900	2400	2500	3500	0	
NILES	7458	1500	53070	38698	13501	4955	8279	0	0
NORTHFIELD	1200	1600	6700	4200	3600	2400	3200	530	
ORLAND	100		600	400	100	1400	300	0	
PALATINE	1600		7600	2200	1000	1700	1500	0	
PALOS	500	600	100	700	700	1400	500	0	
PRUSS-RIVERSIDE	3900	6100	24500	24800	10900	10900	5700	1365	
RICH	100	100	300	4100	800	1800	900	0	
SCHAMBERG	1600	100	500	500	300	1400	800	0	
STICKNEY	518	7722	25711	8159	1649	2324	2943	2397	498
THORNTON	2200	4000	14000	6400	5500	6800	2500	3014	647

Table A.10.2

E M P L O Y M E N T D A T A								
ZONE	CMCEMP	TCCEMP	MECEMP	SRVEMP	GVTEMP	AGSEMP	POLEMP	WIPEMP
WHEELING	700	1100	6100	8100	3100	3500	2500	0
WORTH	3117	4557	5666	14708	9532	5314	3281	648
ADDISON	2000	1500	11000	7700	3400	2200	1900	0
BLOOMINGDALE	600	100	2700	2500	1000	1300	700	500
DOWNS GRUVE	1100	300	3300	4500	4400	7200	2200	0
CLIFF	300	200	4000	3000	3700	1200	1200	0
MILTON	1500	1800	1900	4200	4800	3400	1900	0
NAPERVILLE	500	1100	1000	1200	1800	1100	600	0
WAYNE	500		400	300	800	100	300	0
WINDFIELD	600	300	1300	2300	1900	700	600	0
TRV	1700	800	3100	14600	7700	4300	2900	0
ARORA	1400	2300	16000	7800	6000	3300	2500	1112
DUNDEE	200		1900	1500	700	1500	600	0
ELGIN	1000	1000	7700	6000	4600	5400	1700	0
GENE A-RATAVIA	200		6400	1500	1100	1800	900	0
ST. CHARLES	100		3800	1100	1600	1600	700	350
CLARK	100	300	1900	2200	600	500	600	0
DEERFIELD-WORFD	1300	400	4600	3700	3200	3600	2900	0
ELA			1400	200	100	300	400	0
LIBERTYVILLE	200	900	4700	1600	1400	1200	800	100
SHIELDS	200	100	3800	1400	5000	4900	1400	2423
LENNON			400	500	500	400	500	0
WALKEGAN	1600	1800	17800	6500	5200	3200	2300	8068
OLPAGE			1300	400	200	600	300	650
FRANKFERT			700	200	200	200	200	283
JOLIET	3200	5700	13000	9000	6500	4100	2600	12439
LOCKPORT	1100	700	2000	1300	1100	2100	600	1081
NEW LENOX		300	100	400	200	400	200	0
PLAINFIELD	100		1000	500	300	300	200	2
HOMER				200	100	200	200	0
WHEATLAND				100		100		0
CALUMET	3386	5315	37875	12284	9267	9644	4336	28750
CENTER	125	335	235	837	993	694	176	0
HOBART	169	317	127	1419	518	1123	200	0
NORTH	4633	7074	57911	14738	10895	7658	5733	38813
ROSS	326	5	262	1487	1447	532	208	0
ST. JOHN	352	100	210	1202	1132	395	187	0
PRIDE-WISCONSIN	736	548	8704	1084	840	1363	732	8150

Table A.10.3

TOTAL ZONE LAND AREA AND POPULATION DATA

ZONE	LDAREA	PPIN70	PCTWHT
LOGAN	7.2	83835	.620
JEFFERSON PARK	11.4	123903	.993
ROGERS PARK	16.3	471450	.951
HELMINT CREEK	12.0	174230	.996
LAKE VIEW	14.5	362932	.948
ASTIN	13.5	324878	.453
WEST TOWN	6.0	125442	.690
LAWNDALE	11.2	186482	.520
LOWER WEST SIDE	8.0	101272	.786
DOUGLAS	6.8	178095	.205
CHICAGO LAWN	15.0	159811	.994
WASHINGTON PARK	16.2	397328	.275
CHATHAM	18.0	286457	.218
ROSELAND	12.5	132144	.496
RIVERDALE	16.5	81501	.784
SOUTH CHICAGO	16.6	95028	.861
BARRINGTON	36.0	7607	.997
BROWN-CORRIGAN	14.3	182071	.994
BLOOM	46.3	94757	.864
BREMEN	37.4	93906	.854
ECK GROUP	28.1	77169	.992
EMANSTON	7.6	79808	.821
HANDLER	33.1	34150	.990
LEMON	21.0	8314	.996
LEYDEN	36.0	174325	.995
LYONS	36.6	171837	.969
MAINE	28.3	153583	.994
NEW RIVER	16.0	65365	.982
NILES	22.5	119480	.990
NORTHFIELD	34.5	65557	.992
ORLAND	36.0	15028	.979
PALATINE	36.0	54817	.995
PALOS	35.1	33100	.996
PRUSS-ROUSSELS	36.0	204652	.929
RICH	36.2	44801	.981
SCHAMBERG	30.3	50541	.994
STICKNEY	18.0	103410	.963
THORNTON	47.1	188014	.880

Table A.10.4

TOTAL ZONE LAND AREA AND POPULATION DATA			
ZONE	LDAREA	POPIN70	PC1WHT
WHEELING	36.0	119218	.994
WORTH	35.8	125463	.989
ADDISON	34.2	72280	.995
BLOOMINGDALE	34.6	36654	.994
DOWNERS GROVE	50.5	94637	.992
ELISE	35.8	49061	.990
MILTON	34.7	75848	.986
NAPERVILLE	35.4	13028	.995
WAYNE	36.0	5485	.996
WINFIELD	35.8	23001	.995
WYOMING	35.2	122187	.992
YORK	34.9	95176	.941
DAVIDSON	35.8	34575	.996
ELGIN	31.9	58972	.950
GENEVA-BATAVIA	34.8	24105	.970
ST. CHARLES	35.4	20352	.973
LIBERTY	23.9	9097	.997
DEERFIELD	29.5	64459	.983
ELA	35.8	12208	.994
LIBERTYVILLE	36.0	25577	.994
SHIELDS	18.0	65093	.892
VERNON	35.8	12835	.990
WAKEGAM	21.0	16680	.841
W. PAGE	36.6	20037	.994
FRANKFORT	36.2	9633	.997
JOLIET	36.0	96001	.870
LOCKPORT	36.3	33354	.857
NEW LENOX	35.9	10049	.998
PLAINFIELD	35.2	11028	.997
ROMER	35.9	6686	.993
WHEATLAND	35.6	1794	.997
CALUMET	63.0	215940	.559
CENTER	39.8	21946	.994
HOBART	26.9	40825	.995
NORTH	57.4	273480	.907
ROSS	49.0	28845	.998
ST. JOHN	39.3	16829	.997
PRITCHARD-STR	68.9	42023	.996

Table A.10.5

LAND AREA DATA									
ZONE	RSDREA	MFGREA	PLCREA	TRRSREA	PKLAKE				
	COMREA	NSIREA	AYTREA	SIREA					
LOOP	.5	1.2	.5	.5	0.3	.3	1.9	2.0	4.0
JEFFERSON PARK	4.9	.5	.3	.4	1.4	.1	.3	3.3	
ROGERS PARK	6.7	1.1	.2	1.0	2.3	.3	.3	4.4	3.0
BELMONT-CRAGIN	5.55	.9	.9	.3	.5	.1	.35	3.4	
LAKE VIEW	5.3	1.1	1.1	.5	1.1	.4	.5	4.5	3.2
WINSTON	4.7	.9	1.2	.4	.8	.4	1.0	4.0	
WEST TOWN	1.2	.7	.7	.5	.15	.4	.25	2.1	
LAWDALE	2.9	.6	1.9	.4	.3	.9	1.6	2.7	
CYBER WEST SIDE	1.4	.8	1.3	.2	.2	.5	1.8	1.8	
DOUGLAS	1.9	.6	.35	.5	.45	.3	.6	2.1	3.3
CHICAGO LAWN	6.3	1.1	1.0	.3	.9	.5	1.1	3.8	
WASHINGTON PARK	5.7	1.0	.4	.9	1.7	.7	1.2	4.5	2.6
CHATHAM	7.8	1.0	.8	.4	.7	.6	1.3	5.4	
ROSELAND	6.2	.5	.7	.5	.4	.7	.7	4.1	
RIVERDALE	2.5	.7	.7	.3	1.8	5.1	1.6	1.9	
STUYV. CHICAGO	2.7	.6	2.9	.4	1.1	3.7	2.7	2.4	1.6
BIRMINGHAM	3.2	0.1		.1	5.4	24.1	.4	1.5	
BROWN-CORR-ORISKANY	7.5	.9	1.0	.4	.4	.1	.8	3.1	
BROWN	8.5	.8	1.4	.9	7.5	22.0	1.8	3.2	
BREMEN	10.0	.5	.3	.4	7.6	12.9	.6	4.0	
BIRK GROVE	7.0	.8	2.2	.9	5.5	7.6	1.0	3.2	
ELANSTON	3.9	.3	.3	.7	0.5	.1	.2	1.4	1.2
HARDER	4.0	.2	.3	.4	6.1	17.8	2.2	2.1	
LEMON	1.5	.1	.1	.5	4.2	12.3	.9	.6	
LEYDEN	9.2	1.2	3.9	.8	5.5	1.7	7.4	5.1	
LIONS	11.1	.8	2.6	1.5	4.1	7.6	3.8	4.4	
MAINE	11.9	1.3	1.1	1.1	3.7	2.4	2.0	4.4	
NEW BRIDGE	8.9	.4	.1	.7	3.4	.1	.3	2.2	0.6
NILES	9.0	1.2	2.3	.7	4.1	1.0	.7	3.5	
NORTHFIELD	11.0	.7	.7	2.5	6.9	8.6	.9	2.9	
ORLAND	2.7	.1	.1	1.2	5.1	24.7	.6	1.2	
PALM LINE	9.6	.4	.5	.9	6.3	14.8	.2	2.7	
PALMS	6.2	.2	.1	.5	16.5	8.2	1.0	1.8	
PROVISO-RIVERSIDE	13.5	1.3	2.1	1.7	7.1	1.9	2.2	5.6	
RICH	5.6	.3	.2	.9	4.8	21.3	.7	2.4	
SCHAMBERG	6.1	.5	.2	.3	.4	19.6	.5	2.6	
STICKNEY	5.6	.5	1.8	.5	.6	2.8	3.6	2.6	
THORNTON	13.6	2.0	1.8	1.2	6.1	11.2	5.0	5.8	

Table A.10.6

LAND AREA DATA								
ZONE	RSDREA	MFGREA	PLCREA	TRSREA	PRLAKE	COMREA	NSTREA	AVTREA
WHEELING	13.3	.9	.6	1.4	3.8	11.6	1.1	3.2
WORTH	13.8	1.3	.9	1.2	4.9	6.8	1.7	4.9
ADDISON	7.2	.9	.8	.7	2.6	14.6	3.0	4.0
BIRMINGDALE	5.4	.3	.3	.4	3.0	21.6	1.1	2.5
DOWNERS GROVE	15.3	.7	.3	6.3	2.1	18.2	1.0	6.0
LISLE	8.1	.5	.2	.8	3.9	17.9	.9	3.3
MILTON	10.9	.7	.3	1.0	4.0	13.1	.8	3.8
NAPERVILLE	2.0	.4	.2	.2	1.2	27.9	1.3	1.9
WAYNE	2.3	.1	.2	.1	2.6	27.5	1.8	1.4
WINFIELD	4.4	.3	.3	9.3	3.9	14.7	.8	2.0
YORK	13.7	1.5	.2	1.4	2.6	9.0	.8	5.8
ALBANY	9.0	.7	1.3	1.1	1.9	15.6	1.3	3.4
DUNDEE	4.2	.3	.2	.3	1.0	25.7	1.5	1.8
ELGIN	6.1	.4	.6	.8	.9	19.2	1.3	2.0
GENE A-BATAVIA	4.3	.7	.5	1.4	1.0	25.0	.4	1.5
ST. CHARLES	4.8	.1	.3	2.0	.7	23.8	.7	1.9
CUBA	2.8	.1		.2	.6	17.6	.1	1.2
DEERFIELD-WDREFO	10.1	.5	.4	2.4	.9	11.2	.6	3.1
ELA	2.7	.2		.1	.3	28.8	.2	1.8
LIBERTYVILLE	2.8	.4	.2	.2	1.6	27.0	.8	1.9
SHIELDS	5.2	.3	.4	3.4	1.4	4.7	.4	1.6
VERNON	3.5	.3	.1	.3	1.7	27.1	1.8	1.5
WACKEGAN	5.1	.8	.7	.4	2.3	8.0	.4	2.1
W. PAGE	1.9	.1	.2	.2	.3	29.3	2.3	1.4
FRANKFORT	2.3	.1	.1	.2	.7	30.4	1.2	1.3
JOLIET	8.9	.8	1.2	1.3	1.0	15.7	3.1	3.0
LOCKPORT	3.6	.5	.5	3.5	.7	22.4	3.2	1.2
NEW LENA	2.4	.1		.2	1.5	28.8	1.4	1.2
PLAINFIELD	2.1	.1	.4	.1	.4	27.3	3.3	1.4
HOMER	2.2				.3	31.7	.7	.7
WHEATLAND	.6					32.8	1.0	.9
CALUMET	12.7	2.8	6.0	2.5	1.3	24.9	5.3	7.4
CENTER	4.0	0.3	0.0	0.2	1.0	32.5	0.3	1.4
HOBART	4.9	0.4	0.1	0.5	0.3	17.8	0.7	2.2
NORTH	11.3	2.1	11.2	1.9	1.7	18.1	4.2	6.9
ROSS	4.9	0.5	0.1	0.5	0.6	39.5	0.7	2.2
ST. JOHN	3.5	0.5	0.2	0.5	0.6	31.6	0.8	1.6
PRITGE-WSTCHSTR	7.6	0.6	4.0	0.4	9.5	41.5	1.5	3.8

Table A.10.7

ZONE	W A T E R V A R I A B L E S					
	F1	F5	L	D3	D5	M
ADD	2570	111	5.7	500	218	0.3
JEFFERSON PARK						
ROGERS PARK	1280	64				0.5
BELMONT CRAGIN						
LAKEVIEW	1480	74	3.3	24	2	
AUSTIN						
NEAR WEST SIDE	400	20	1.9	119	49	
LAWDALE	2310	87	3.3	162	47	
LOWER WEST SIDE	1540	58	3.0	173	64	
DODD	280	11	0.4	37	16	
CHICAGO LAWN						
CASSINGTON PARK						
CHATHAM						
ROSELAND						
CALMET	1905	118	7.4	54	4	
SOUTH CHICAGO	1280	91	8.1	1913	1418	1.4
BARRINGTON						
BRVH-CORR-OKPK						
BLOOM						
BREMER						
ELK GROVE						
EVANSTON	332	26				0.2
HANOVER						
LEMON	4543	119	3.3	133	37	
LEVITT						
LYONS	9972	208	7.2	354	102	
MAINE						
NEW TRIER						
NILES	32	16				
NORTHFIELD						
ORLAND						
PALATINE						
PALES	747	41	2.3	17	1	
PROVISO						
RICH						
SCHAUMBURG						
STICKNEY	3954	113	3.3	162	47	
THORNTON	320	23	1.6	12	1	

Table A.10.9

EMPLOYMENT AND ACCESSIBILITIES

ZONE	AWUPL2	ANWPL2	ADNFG2	ASRVS2	ADTHR2
LOOP	313.	335.	26480.	13495.	23552.
JEFFERSON PARK	142.	639.	22610.	11725.	20541.
ROGERS PARK	151.	284.	20781.	13518.	19987.
RELMONT CRAGIN	181.	233.	23847.	14167.	23366.
LAKEVIEW	205.	409.	31251.	30674.	38149.
AUSTIN	267.	715.	34233.	24134.	34396.
NEAR WEST SIDE	290.	380.	71405.	90065.	96220.
LAWDALE	410.	571.	33216.	21548.	32574.
LOWER WEST SIDE	430.	486.	41240.	37759.	47288.
DOUGLAS	501.	524.	37095.	39738.	47219.
CHICAGO LAWN	579.	720.	19609.	10387.	18014.
WASHINGTON PARK	681.	419.	21055.	15685.	22491.
CHATHAM	1237.	596.	12954.	10036.	15189.
ROSELAND	1386.	464.	11233.	6910.	12785.
CALUMET	1717.	721.	8311.	4911.	9457.
SOUTH CHICAGO	789.	270.	7012.	4805.	7980.
PARRINGTON	48.	64.	2451.	1115.	2557.
BRUNN-CORD-OKPK	305.	585.	24447.	12415.	22556.
ALDGM	718.	180.	2670.	1561.	3065.
AREMEN	461.	289.	4133.	2407.	4778.
FLK GRO E	80.	127.	7277.	3117.	6774.
EVANSTON	112.	165.	14248.	8031.	14930.
HANDOVER	59.	70.	2630.	1282.	2809.
ELEMENT	240.	227.	3408.	1981.	3963.
EYLEN	112.	219.	9334.	4768.	9749.
LYONS	225.	256.	8978.	4621.	9090.
MAINE	96.	189.	12271.	5062.	10668.
NEW TRIER	86.	151.	9170.	5404.	9496.
NILES	110.	213.	11083.	8835.	12840.
NORTHFIELD	76.	122.	6758.	3642.	7426.
ORLAND	281.	213.	3144.	1931.	3700.
PALESTINE	56.	88.	3414.	1591.	3617.
PAIDS	343.	406.	5540.	3067.	5997.
PROLISO	251.	485.	12557.	6236.	11498.
RICH	354.	243.	2514.	1454.	2803.
SCHAUMBURG	67.	104.	4238.	1812.	4164.
STICKNEY	448.	579.	18778.	9610.	18234.
THORNTON	1240.	364.	4425.	2569.	4942.

Table A.10.10

EMPLOYMENT AUTO ACCESSIBILITIES

ZONE	AWUPL2	ANWPL2	ADMFG2	ASRV52	AOTHR2
WHEELING	65.	124.	5105.	2360.	5030.
WORTH	522.	390.	7378.	4116.	7600.
ADDISON	108.	189.	9369.	3809.	8378.
BLOOMINGDALE	84.	104.	4465.	2140.	4595.
DOWNERS GROVE	241.	337.	4795.	2575.	5074.
Lisle	146.	145.	3213.	1852.	3786.
WILTON	109.	143.	4016.	2190.	4587.
NAPERVILLE	100.	115.	2654.	1423.	2819.
WAYNE	74.	89.	2842.	1434.	3087.
WINFIELD	84.	97.	2824.	1506.	3039.
YORK	158.	260.	6862.	3320.	6869.
ALTON	72.	59.	1546.	848.	1663.
DUNDEE	41.	47.	1653.	834.	1803.
ELGIN	55.	50.	1636.	829.	1746.
GENEVA-RATAJIA	69.	84.	2100.	1089.	2171.
ST. CHARLES	51.	58.	2051.	1033.	2218.
TOURNAI	41.	63.	1830.	892.	1885.
DEERFIELD-WORREN	58.	176.	3441.	2033.	3868.
FLA	46.	89.	2480.	1201.	2624.
LIBERTYVILLE	44.	265.	1962.	1255.	2387.
SHIELDS	48.	210.	2441.	1295.	2569.
BERNARD	52.	139.	3320.	1717.	3691.
WATKINSON	34.	78.	1225.	805.	1431.
DUPAGE	170.	150.	2563.	1506.	2961.
FRANKFORT	240.	159.	1997.	1226.	2465.
JOLIET	120.	60.	1316.	774.	1506.
LOCKPORT	269.	259.	1974.	1184.	2354.
NEW LENOX	298.	267.	1828.	1123.	2234.
PLAINFIELD	184.	149.	1516.	883.	1758.
HOMER	261.	209.	2471.	1459.	2921.
WHEATLAND	137.	112.	2016.	1119.	2207.
CALUMET	1028.	158.	2280.	1388.	2539.
CENTER	399.	69.	1109.	715.	1317.
HODART	1394.	76.	1892.	1187.	2358.
NORTH	1003.	212.	3026.	1912.	3550.
ROSS	885.	82.	1584.	981.	1948.
ST. JOHN	1037.	173.	2177.	1234.	2447.
PRITCHESTON	398.	49.	1126.	771.	1358.

Table A.10.11

POPULATION AUTO ACCESSIBILITIES
AND CONTROLLED AIR POLLUTER INVENTORY

ZONE	AWHPP2	ABLPP2	CONTROLLED	
			POLEMP	WUPEMP
COOP	84862.	43322.	900	
JEFFERSON PARK	90941.	12519.		
ROGERS PARK	71724.	12911.		
BELMONT CRAGIN	91887.	24857.	6455	
LAKEVIEW	89051.	28614.	1450	
AUSTIN	106394.	24401.	106	
NEAR WEST SIDE	115994.	50023.		
LAWNDALE	94049.	42890.	3413	268
LOWER WEST SIDE	92558.	84713.	581	281
DOUGLAS	78114.	61544.	4400	
CHICAGO LAWN	62280.	39842.		
WASHINGTON PARK	58729.	52079.		
CHATHAM	57367.	46175.	450	
ROSELAND	54773.	42573.		
CALUMET	45898.	27824.	5880	3500
SOUTH CHICAGO	31375.	22397.	14757	10300
BARRINGTON	14164.	1293.		
BROWN-CORR-OXPK	79320.	34881.	14985	
BLOOM	17369.	4627.	5500	500
BREVEN	25502.	7031.		
ELK GROVE	29874.	2940.	130	
EVANSTON	61596.	6775.	1000	
HANOVER	14787.	1476.		
HEMONT	20944.	3834.		
HEYDEN	53512.	7998.		
HYONS	42499.	9775.	10848	3200
MAINE	39872.	4685.	35	
NEW TRIER	36971.	4486.		
NILES	61687.	7815.		
NORTHFIELD	33128.	3271.		
ORLAND	20486.	4766.		
PALATINE	18978.	1726.		
PAULS	30916.	6995.		
PROVISO	50392.	10907.		
RICH	15972.	4174.		
SCHAMBERG	20843.	1996.		
STICKNEY	65385.	20745.	2267	217
THORNTON	24816.	9109.	219	219

Table A.10.12

POPULATION AUTO ACCESSIBILITIES
 AIRPORTS INVENTORY

ZONE	AQHPP2	ABLPP2	CONTROLLED	
			POLEMP	WUPEMP
WHEELING	23496.	2323.		
WORTH	34796.	15386.	592	25
ADDISON	32394.	4063.		
BLOOMINGDALE	23094.	2430.	700	
DOWNERS GROVE	25049.	4464.		
EISE	19479.	2642.		
MILTON	22652.	2733.		
NAPERVILLE	15342.	1863.		
NAYNE	16485.	1684.		
MINFIELD	15962.	1823.		
NEPA	31704.	4853.		
AURORA	8237.	1181.		
DUNDEE	8985.	1009.	30	
ELGIN	9623.	1035.	335	
GENEVA-RATAVIA	11412.	1340.		
ST. CHARLES	11168.	1242.		
CLARK	10104.	1081.		
DEERFIELD-WORREN	18294.	2137.		
ELA	12549.	1337.		
IRBERTVILLE	11986.	1556.		
SHIELDS	12475.	1521.		
BERNARD	19358.	1774.		
AMNEGAN	6702.	978.	5304	304
DUPAGE	15560.	2482.	475	475
FRANKFORT	13191.	2997.		
MOBILET	7835.	1604.	5505	5380
LOCKPORT	12396.	2200.	1686	1061
NEW LENOX	11660.	2442.		
PLAINFIELD	9100.	1629.		
HOMER	15428.	3100.		
WHEATLAND	11819.	1721.		
CALMET	13823.	3093.	28650	28375
CENTER	7004.	1942.		
HOBART	11721.	4834.		
NORTH	17091.	7215.	38813	35974
ROSS	12472.	3413.		
ST. JOHN	13160.	3864.		
PRIGE-WSTCTR	6330.	2167.	8150	8150

Table A.10.13

RAIL RAPID TRANSIT POPULATION AND
EMPLOYMENT ACCESSIBILITIES
(*10**-3)

ZONE	ATSNUP	ATSMFG	ATSSRV	ATSDIR	ATSWHP	ATSBLP	ATSWUP
LOOP	89	18782	11074	17413	635754	24669	52
JEFFERSON PARK	2	559	734	763	1266	207	
ROGERS PARK	8	8408	10708	11008	18065	3008	
BELMONT CRAGIN		221	285	298	459	76	
LAKEVIEW	13	16131	27551	26857	21633	4838	1
AUSTIN	40	10391	15256	15530	12623	3429	1
NEAR WEST SIDE	13	43098	72803	70180	21189	9008	6
LAWNDALE	2	2108	3119	3160	2077	753	1
LOWER WEST SIDE	5	4049	5784	5967	3747	1659	1
DOUGLAS	18	7786	13207	13222	6903	8435	53
CHICAGO LAWN							
WASHINGTON PARK	44	7711	11903	12170	8678	7846	110
CHATHAM	54	19	1645	2003	4138	5426	196
ROSELAND	55	1248	1356	1878	4787	5362	144
RIVERDALE	33	961	1077	142	3320	4354	82
SOUTH CHICAGO	10	875	113	142	2478	4462	9
BARRINGTON							
BROWN-CORR-CORP	5	4626	5007	5769	7153	1676	
B. CRY	5	109	169	116	508	381	10
BREKEN							
ELK GROVE							
EVANSTON	4	2462	3293	3657	12306	1170	
HANDLER							
LEMONT							
LEYDEN							
LYONS							
MAINE							
NEW TRIER		128	192	194	439	72	
NILES		157	247	243	607	96	
NORTHFIELD							
ORLAND							
PALATINE							
PALOS							
PROVISO	3	337	371	423	748	107	
RICH	24	450	487	656	1634	1518	39
SCHALMBERG							
STICKNEY							
THORNTON	19	509	704	966	2004	2677	61

ALL REMAINING ZONES HAVE NO RAIL TRANSIT SERVICE

Table A.10.14

COMPUTER PAYL POPULATION AND
EMPLOYMENT ACCESSIBILITIES
(*10**3)

ZONE	ARRWHP	ARRBLD	ARRSR	ARRDTR	ARRMFG	ARRWUP	ARRINCP
LOOP	3192.6	1789.4	0.0	0.0	0.0	0.0	0.0
JEFFERSON PARK	1673.9	12.6	395.6	523.2	468.2	0.0	16.9
ROGERS PARK	533.4	61.8	171.2	199.0	139.1	0.0	0.1
BEHRENT CROWN	1579.2	13.2	684.2	847.8	580.0	0.0	0.0
LAKEVIEW	940.5	41.2	759.4	825.4	421.4	0.0	0.0
ARISTIN	918.8	5.3	476.3	517.7	264.3	0.0	0.0
WEST TOWN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LAWDALE	366.2	11.6	138.6	156.6	88.4	0.1	0.1
LOWER WEST SIDE	281.4	40.7	273.4	297.1	151.7	0.0	0.0
DOUGLAS	54.6	46.5	30.4	35.0	16.9	0.0	0.0
CHICAGO LAWN	48.1	0.5	20.8	22.8	15.0	0.0	0.0
WASHINGTON PARK	397.7	133.1	825.5	892.8	459.9	0.0	0.1
CHATHAM	24.4	10.1	32.1	35.2	17.8	0.0	0.0
ROSELAND	33.9	5.1	19.7	23.1	12.4	0.0	0.0
RIVERDALE	155.3	32.5	399.8	322.1	164.7	0.0	0.0
SOUTH CHICAGO	368.0	68.8	149.5	165.3	85.8	0.7	0.1
BARRINGTON	0.0	0.0	25.1	39.9	32.4	0.0	0.2
BROWN-CORR-CKPK	1033.1	54.0	168.3	191.0	97.3	0.1	0.1
BLOOM	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BREMEN	18.5	0.9	42.6	52.1	29.9	0.8	0.2
E K GROVE	378.5	2.2	119.8	191.6	140.0	0.0	0.7
EMANSTON	787.3	25.2	447.0	531.0	333.8	0.0	0.5
HANDLER	113.4	0.0	87.5	148.6	205.2	0.0	4.3
LEMON	6.3	1.0	8.0	9.9	8.8	0.7	1.8
LEDFEN	672.1	8.0	398.8	419.1	320.6	0.0	44.7
LEONS	2659.4	24.8	483.8	864.2	620.4	0.4	20.4
MAINE	788.8	5.1	370.1	491.9	378.6	0.0	2.5
NEW BRIER	822.0	44.1	672.2	691.1	409.4	0.0	1.0
NILES	305.6	3.1	205.2	306.0	231.0	0.0	7.7
NORTHFIELD	209.7	3.8	193.5	385.1	387.1	0.0	5.7
ORLAND	0.0	0.0	7.6	11.2	5.4	0.0	0.1
PALATINE	20.0	0.0	134.1	197.1	179.6	0.0	1.0
PALOS	1.1	0.0	9.9	19.7	9.3	0.0	0.2
PRVSD-RVRSDEFS	2901.2	33.4	478.9	582.5	429.8	0.3	4.5
RICH	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SCHAUMBURG	0.0	0.0	0.0	0.0	0.0	0.0	0.0
STICKNEY	14.5	0.8	17.1	18.6	9.5	0.0	0.0
THORNTON	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A.10.15

COMMUTER RAIL POPULATION AND
EMPLOYMENT ACCESSIBILITIES
(*10**3)

ZONE	ARRWHP	APRBLP	ARRSRV	ARROTR	ARRMEG	ARRWUP	ARRNUP
WHEELING	187.6	1.0	192.7	315.9	251.7	0.0	1.6
WORTH	9.7	0.0	38.0	45.2	28.2	0.0	0.1
ADDISON	155.0	3.4	192.2	385.7	580.7	0.0	10.2
BLOOMINGDALE	112.8	3.6	123.2	241.8	336.1	0.0	7.2
DOWNERS GROVE	626.3	10.6	729.7	1301.8	1152.3	83.8	260.2
Lisle	78.5	2.7	193.3	366.7	195.7	9.2	29.2
MILTON	91.0	0.9	206.9	363.8	197.5	0.0	4.1
NAPERVILLE	48.4	2.0	60.8	111.6	56.8	2.9	9.4
WAYNE	142.1	2.6	24.2	47.1	61.4	0.0	1.7
WINFIELD	33.7	1.0	131.5	214.1	85.2	0.0	1.3
YORK	410.6	5.7	274.0	459.4	314.7	0.0	8.8
A. RRA	0.0	0.0	53.6	100.0	65.9	2.1	6.8
DANDEE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ELGIN	0.0	0.0	106.0	186.7	224.7	0.0	5.1
GENEVA-BATAVIA	0.0	0.0	38.1	65.8	38.8	0.0	0.7
ST. CHARLES	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CHBA	0.0	0.0	25.1	39.9	32.4	0.0	0.2
DEEPFELD-WDRED	408.0	34.2	411.6	533.1	417.1	0.0	4.4
EIA	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LIBERTYVILLE	0.0	0.0	49.5	91.0	81.3	0.0	1.5
SHIELDS	121.9	23.0	153.0	231.0	132.9	0.0	0.1
VERNON	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WAUKEGAN	0.0	0.0	81.0	111.0	61.1	0.0	5.1
DUPAGE	0.0	0.0	0.0	0.0	0.0	0.0	0.0
FRANKFORT	13.3	1.5	20.7	22.1	12.1	0.2	0.0
JOLIET	0.0	0.0	22.3	26.8	15.9	0.5	0.8
LOCKPORT	7.5	1.1	6.4	7.3	5.1	0.3	0.9
NEW LENOX	17.5	2.6	15.2	18.9	10.2	0.2	0.2
PLAINFIELD	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WHEATLAND	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CALUMET	89.6	0.1	221.0	276.6	176.6	78.6	4.9
CENTER	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HOBART	0.0	0.0	17.6	29.6	21.2	20.6	0.7
NORTH	276.0	182.3	249.4	286.6	179.5	33.5	9.2
ROSS	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ST. JOHN	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PRTGE-WSICHSTR	0.0	0.0	251.4	316.1	185.1	79.9	3.3

Table A.10.16

AIR FREIGHT AND PASSENGERS AND AUTO ACCESS

ZONE	AIRFT	AAIRP2	AIRFT	AIRPS
LOOP	16094.	48651.		
JEFFERSON PARK	56231.	167262.		
RODGERS PARK	23737.	70852.		
BEIMONT CRAGIN	48054.	143398.		
LAKEVIEW	22197.	66542.		
AUSTIN	31169.	54028.		
NEAR WEST SIDE	20975.	63354.		
LAWNDALE	41915.	129092.		
OWER WEST SIDE	25097.	76857.		
DOUGLAS	16614.	50657.		
CHICAGO LAWN	84239.	262421.		
WASHINGTON PARK	17670.	54183.		
CHATHAM	13968.	42835.		
ROSELAND	12220.	37470.		
CALUMET	8024.	24490.		
SOUTH CHICAGO	6780.	20629.		
PARRINGTON	9604.	28587.		
BROWN-CORRO-OKPK	42008.	127686.		
BLOOM	3165.	9579.		
BREMEN	6385.	19425.		
FLK GROVE	92139.	273676.		
EVANSTON	20714.	61724.		
HANOVER	10903.	32457.		
LEMONT	4233.	24873.		
LEYDEN	2028.	6354.	3028353.	7800097.
LYONS	30030.	91964.		
MAINE	149155.	442976.		
NEW TRIER	21052.	62657.		
NILES	38788.	115400.		
NORTHFIELD	28763.	85527.		
ORLAND	6266.	19006.		
PALATINE	17879.	53174.		
PAINDS	12980.	39611.		
PROVISO	46207.	138540.		
RICH	3628.	10982.		
SCHAUMBERG	25029.	74427.		
STICKNEY	11228.	33327.	475460.	1486494.
THORNTON	4924.	14956.		

Table A.10.17

AIR FREIGHT AND PASSENGERS AND AUTO ACCESS

ZONE	AIRFT	AIRP2	AIRFT	AIRPS
WHEELING	29109.	86530.		
WORTH	16099.	49508.		
ADDISON	144409.	428951.		
BLOOMINGDALE	28128.	83676.		
DOWNERS GROVE	13965.	42046.		
ELISE	10164.	30427.		
ELIZON	18457.	55031.		
HAVERVILLE	6733.	20130.		
WAYNE	11494.	34238.		
WINFIELD	9279.	27684.		
YORK	35531.	105959.		
ALP RA	4362.	13037.		
DUNDEE	5603.	16691.		
ELGIN	5885.	17537.		
GENEVA-RATAVIA	5405.	16134.		
ST. CHARLES	6086.	18145.		
CLARK	4887.	20505.		
DEERFIELD-WORREN	11952.	35574.		
FLA	9221.	27444.		
HAIRFRTYVILLE	6125.	18240.		
SHIELDS	6349.	18911.		
BERNON	12028.	35788.		
WALLEGAN	3683.	10978.		
DUPAGE	6499.	19513.		
FRANKFORT	3722.	11250.		
JOHNET	2997.	9015.		
LOCKPORT	4321.	12992.		
NEW LENNOX	3444.	10382.		
PLAINFIELD	3422.	10267.		
HOMER	5339.	16113.		
WHEATLAND	4772.	14299.		
CALUMET	2320.	7002.		
CENTER	1462.	4404.		
HOBART	1738.	5236.		
NORTH	3284.	9938.		
ROSS	1656.	4997.		
ST. JOHN	2138.	6454.		
PRIGE-WSTCTR	1512.	4550.		

Table A.10.18

ACCESSIBILITIES TO SHIFTER VARIABLES					
ZONE	AFLOW	ADEPTH	ATSFLW	ATSDPT	ARRAIR
ADOP	580.	32.	20601	14024	
JEFFERSON PARK	360.	10.	400	386	
ROGERS PARK	357.	13.	6336	5453	
RELMONT CRAGIN	439.	15.	149	152	
LAKEVIEW	536.	29.	10477	15246	
AUSTIN	759.	31.	5322	9312	
NEAR WEST SIDE	1202.	57.	23339	42668	
LAWNDALE	956.	41.	1190	2010	
LOWER WEST SIDE	1067.	49.	2180	3918	
DOUGLAS	907.	56.	3300	5962	
CHICAGO LAWN	1267.	39.			
WASHINGTON PARK	643.	49.	34549	14610	
CHATHAM	527.	74.	32033	13492	
ROSELAND	701.	68.	48565	8181	
CALUMET	387.	99.	12237	5932	
SOUTH CHICAGO	369.	24.	14113	501	
BARRINGTON	109.	2.			
BRWL-CORD-OKPK	775.	23.			
ALDOM	204.	26.	2714	588	
BREKEN	358.	20.			
ELK GROVE	133.	4.			
EVANSTON	250.	8.	2702	1383	
HANDOVER	148.	3.			12150
LEMONT	601.	11.			53
BERGEN	199.	6.			
YONS	480.	14.			178
MAINE	169.	6.			
NEW TRIER	154.	5.	127	83	
NILES	237.	7.	176	98	
NORTHFIELD	116.	4.			
ORLAND	442.	12.			
PAIATINE	91.	3.			
PAIGS	760.	17.			
PRO. ISO	573.	14.	125	193	
RICH	208.	14.	10627	2486	
SCHAUMBURG	123.	3.			
STICKNEY	800.	26.			
THORNTON	350.	50.	16635	3904	

Table A.10.19

A C C E S S I B I L I T I E S T O S H I F T E R V A R I A B L E S					
ZONE	ΔFLOW	ΔDEPTH	ΔTSFLW	ΔTSDPT	ΔRAIR
WHEELING	96.	4.			
WORTH	508.	25.			
ADDYSEN	201.	6.			46800
BLOOMINGDALE	167.	4.			20647
DOWNERS GROVE	678.	11.			
LISLE	467.	7.			
MILTON	250.	5.			
NAPERVILLE	308.	5.			
WAYNE	180.	3.			3510
WINFIELD	226.	4.			
YORK	358.	8.			
AURORA	183.	3.			
DUNDEE	89.	2.			
ELGIN	137.	2.			12388
GENEVA-BATAVIA	182.	3.			
ST. CHARLES	152.	2.			
CLARA	69.	2.			
DEERFIELD-WORFO	73.	3.			
FLA	66.	2.			
IRERTYVILLE	49.	3.			
SHIELDS	51.	3.			
ERNON	69.	3.			
WAINWEGAN	36.	2.			
DUPAGE	603.	8.			
FRANKFORT	282.	9.			
JOLIET	414.	6.			30
LOCKPORT	562.	6.			38
NEW LENNEX	563.	7.			
PLAINFIELD	595.	6.			
HOMER	820.	11.			
WHEATLAND	477.	6.			
CALUMET	180.	34.			
CENTER	83.	15.			
MORRIS	164.	57.			
NORTH	192.	49.			
ROSS	130.	35.			
ST. JOHN	178.	37.			
PRITGE-WESTCT	76.	16.			

Table A.10.20

ACCESSIBILITIES TO SHIFTER VARIABLES

ZONE	APLCRA	ATSPRA	ARRPRA	ARRFLW	ARRDPT
LOOP	1.36	776.0	79.2		
JEFFERSON PARK	1.72	22.3	66.6	2323	195
ROGERS PARK	1.40	338.0	20.7	2212	89
REIMONT CRAGIN	1.66	8.2	93.3	4708	363
LAKEVIEW	1.53	543.0	23.7	5140	436
AUSTIN	1.59	229.1	18.0	3242	274
NEAR WEST SIDE	2.53	926.7			
LAWNDALE	1.58	48.1	9.8	1480	102
LOWER WEST SIDE	2.26	75.3	5.4	1850	157
DOUGLAS	1.68	277.2	1.5	206	17
CHICAGO LAWN	1.52		2.0	125	10
WASHINGTON PARK	1.45	301.8	12.7	6085	515
CHATHAM	1.53	159.5	1.2	180	15
ROSELAND	1.56	176.6	2.2	112	10
CALUMET	1.31	105.7	12.8	1812	154
SOUTH CHICAGO	0.88	82.3	7.7	1925	96
BARRINGTON	0.77			177	9
BROWN-CORR-OKPK	1.60	113.3	37.4	1947	117
BLOOM	0.69	22.1			
BREMEN	1.20		0.8	817	22
ELK GROVE	1.26		18.0	843	40
EVANSTON	1.53	197.7	40.0	8497	174
HANOVER	0.78		1.8	347	29
LEMOYNE	1.21		0.1	1989	24
MEYDEN	1.42		35.6	2040	173
LYONS	1.46		69.1	6769	272
MAIZE	1.58		46.9	1748	166
NEW TRIER	1.24	8.2	18.5	10753	199
NILES	1.55	11.5	25.1	1020	87
NORTHFIELD	1.11		3.9	1869	67
ORLAND	1.28			356	4
PALATINE	0.91		7.2	1037	51
PALUS	1.14		0.4	558	6
PROVISO	1.12	7.4	90.1	4773	295
RICH	0.85	61.2			
SCHAUMBERG	1.28				
STICKNEY	1.55		0.7	116	10
THORNTON	0.99	72.4			

Table A.10.21

A C C E S S I B I L I T I E S T O S H I F T E R V A R I A B L E S

ZONE	APLCRA	ATSPRA	ARRPRA	ARRFLW	ARRDPT
WHEELING	1.17		23.1	1456	70
WORTH	1.49		4.6	239	19
ADDISON	1.42		14.1	645	55
BLOOMINGDALE	1.07		11.6	454	39
DOWNERS GROVE	1.22		14.9	266493	3045
EISELE	0.83		2.7	44475	534
MILTON	1.01		13.4	925	78
NAPERVILLE	0.74		1.0	12533	152
WAYNE	0.91		21.0	98	8
WINFIELD	0.77		1.4	589	50
WYOMING	1.22		27.2	1388	118
YORK	0.42			9476	123
DUNDEE	0.57				
ELGIN	0.60			476	40
GENEVA-RATAVIA	0.56			154	13
ST. CHARLES	0.59				
CURA	0.61			177	9
DEERFIELD-WORFEN	0.84		18.2	4857	132
ELA	0.75				
LIBERTYVILLE	0.52			353	18
SHIELDS	0.50		4.9	1898	44
VERNON	0.80				
WAUKEGAN	0.27			987	24
WYOMING	0.78				
FRANKFORT	0.83		0.6	258	9
WOLLIET	0.40			2114	27
LOCKPORT	0.56		.1	1450	17
NEW LENNOX	0.55		0.2	212	8
PLAINFIELD	0.37				
HOMER	1.02				
SHEATLAND	0.52				
CAUMMET	0.42		15.0	11040	2573
CENTER	0.25				
HOBART	0.50			2152	771
NORTH	0.64		12.7	5244	1925
ROSS	0.35				
ST. JOHN	0.46				
PRIGE-WSTCTR	0.17			9844	3219

APPENDIX B: DEVELOPMENT OF THE PROXY VARIABLE FOR CHANNEL CAPACITY

In the process of constructing the spatial econometric model of the Chicago SCA, our investigations led us to the hypothesis that many of the major air polluting industries have their location determined in a large part by the need to be adjacent to the Chicago area's waterways. Two factors are important here. First, major air polluting industries often require substantial volumes of water in the production process. Second, many of these industries ship large volumes of raw materials by low cost per unit weight water transport. In this appendix we are concerned with the second factor. We examine the search for a suitable proxy variable to represent the shipping capacity of a waterway. The proxy variable obtained in this study is used as an independent variable in the regression determining the level of employment in water using air polluting industries for a given zone of our Chicago area spatial model.

B.1 THE CAPACITY OF A COMMERCIAL WATERWAY AS A FUNCTION OF ITS DEPTH

Assume shipping consists of ships in a line all capable of traveling at the same speed and at the same "safe" spacing defined by lock operation characteristics. Then the capacity of a waterway is a function of the capacity of individual vessels. If the capacity of a vessel is a function of its draft, then the capacity of a waterway will be the same function of its channel depth. Thus, we examine the relationship between vessel capacity and draft.

B.2 CARGO CAPACITY AS A FUNCTION OF LOADED DRAFT

Consider the regression model $CC = \alpha D^{\beta} + \epsilon$

where: CC = cargo capacity

D = loaded draft

α and β are constants

Logic suggests that cargo capacity is proportional to the volume of a vessel, and that the volume of a vessel is proportional to the cube of its draft (just as the volume of a cube is proportional to the cube of the length of its side). Thus our initial expectation was that $\beta = 3$.

In order to validate our theoretical expectation, we obtained data on cargo capacity and loaded draft for a random sample of vessels from "Transportation lines on the Great Lakes System."⁴¹

Two econometric methods were then used to examine the problem.

I. The first procedure used was to run OLS for various integral values of β , and to select the value of β with the highest R^2 . The results obtained are presented in the Summary Table. For these OLS regressions, an exponent of 5 gave the highest R^2 , but nearby integral values of the exponent gave results almost as good. The t - statistic on the coefficient α was (not unexpectedly) easily significant (29.9 for an exponent of 5).

Running the regression with a constant term included, so that $CC = C + \alpha D^\beta = \epsilon$, had very little effect on the results. Excluding a rather noticeable outlier increased R^2 to about .93, but an exponent of 5 still gave the highest R^2 .

Ordering the data in terms of increasing loaded draft and examining the resultant Durbin-Watson statistics showed that exponents of 4 and 5 gave the Durbin-Watson statistics closest to the desired value of 2.0 (about 1.4 including and 2.1 excluding the outlier).

Examination of plots of the residuals demonstrates the correlation of error terms as loaded draft increases. The correlation of residuals is greatest for values of the Durbin-Watson statistic far from 2.0. As the integral exponent was varied from one to seven, the pattern of residuals tended to invert itself with the least noticeable pattern occurring at exponents of four and five. Fig. B.1 illustrates the patterns observed for exponents less than four and greater than five. Regardless of the exponent value, heteroscedasticity was present in all forms of the model, with the variance of the residuals increasing as loaded draft increases.

Figure B.1 Patterns of Residuals - Model I

Table B.1

Summary of Results of Regressions of Cargo Capacity on Loaded Draft
(Regressions corrected for Heteroscedasticity are not Presented)

	Exponent	Including Outlyer		Excluding Outlyer	
		R^2	Durbin-Watson	R^2	Durbin-Watson
No Constant Term in the Regression-Model I	1	.5192	.5987	.5789	.6020
	2	.7333	.9451	.8088	1.1292
	3	.8227	1.2400	.8963	1.7633
	4	.8626	1.4102	.9281	2.1873
	5	.8762	1.4094	.9309	2.0190
	6	.8734	1.2818	.9159	1.5479
	7	.8603	1.1200	.8901	1.1650
Constant Included in the Regression-Model I	1	.6887	.8563	.7619	.9723
	2	.7747	1.0642	.8491	1.3517
	3	.8307	1.2658	.9019	1.8190
	4	.8629	1.4060	.9282	2.1934
	5	.8778	1.4440	.9357	2.2163
	6	.8812	1.3910	.9311	1.9327
	7	.8774	1.2928	.9192	1.5931
Logarithmic Form-Model II	2.9	.8402	1.2319	.8396	1.2637
No. of Observations		67		66	

When various weighted regressions were run to eliminate heteroscedasticity the fifth power always retained the highest R^2 value. Although it is not proper to compare R^2 values before and after heteroscedasticity has been eliminated, it is proper to compare results within each group of regressions since identical data was used for all seven regressions of each group before and after weighting.

II. In the application of a second econometric model to our problem, we assume $CC = \alpha D^\beta + \varepsilon$, $\text{var } \varepsilon = \sigma^2 D^\delta$. Thus heteroscedasticity is allowed for, and is assumed proportional to loaded draft raised to an unknown power δ . Taking the natural log of both sides and using a first order Taylor series expansion shows that $\log CC = \log (\alpha D^\beta + \varepsilon) = \log \alpha D^\beta + \frac{\varepsilon}{\alpha D^\beta}$, which may be rewritten

$$\log CC = \log \alpha + \beta \log D + \eta, \text{ var } \eta = \frac{\sigma^2 D^\delta}{\alpha^2 D^{2\beta}}.$$

Letting $\log \alpha = C$ and $\gamma = \delta - 2\beta$, this becomes

$$\log CC = C + \beta \log D + \eta \quad \text{var } \eta = \left\{ \frac{\sigma^2}{\alpha^2} \right\} D^\gamma.$$

First OLS must be run. Then the regression

$$\log \hat{\varepsilon}^2 = \log \left\{ \frac{\sigma^2}{\alpha^2} \right\} + \gamma \log D + \mu$$

must be run on the OLS residuals in order to find $\hat{\gamma}$, an estimate of γ . Finally, the weighted least squares regression

$$D^{\hat{\gamma}/2} \log CC = C (D^{\hat{\gamma}/2}) + \beta (D^{\hat{\gamma}/2} \log D) + \xi$$

must be run, where the error term should now have most of its heteroscedasticity removed. Applying this method to our problem yielded the following results.

Our initial estimate of β before compensating for heteroscedasticity was 2.89, the standard error of .16 being meaningless in view of the heteroscedasticity present. Our estimate of γ was -1.83, with a standard error of 0.53. We then ran the weighted least squares regression described above in order to obtain our final estimate of β , which turned out to be 3.40, with a standard error of .17. (Excluding the outlier changed the above results only slightly.)

The Durbin-Watson statistic for the last regression was 1.30, with quite a noticeable pattern of residuals such as illustrated in Fig. B.2.

Figure B.2 Pattern of Residuals - Model II

Note that the pattern of residuals of Fig. B.2 is similar to the pattern of residuals in Fig. B.1 when the exponent is less than four. This pattern of residuals occurs when the estimated curve has a lower rate of change of increase of cargo capacity (i.e., value of β) as a function of loaded draft than that implied by the pattern of the data. This situation occurs because OLS regression minimizes the sum of the squared residuals from the estimated regression line. If the curve fitting procedure were designed to minimize correlation of residuals ordered by loaded draft then the fitted curve would probably give a higher estimate of β .

Unfortunately, the implications of our empirical research are not clear. Although our initial theory suggests that cargo capacity is a function of the cube of loaded draft, our empirical work does not clearly confirm this. In fact, the empirical results suggest that the appropriate exponent, β , may well be greater than 3.0 and can be used to argue in favor of any integer value of β from three to five. (Since no conclusive range of value of β different from integer values is implied by the research, we confine our analysis to integer values of β .)

Perhaps we could use theory to select a particular value of β (i.e. three). Unfortunately, reconsideration of our initial thinking leads us to the conclusion that values of β in excess of three may be quite reasonable. For example, if the length of a vessel increases more rapidly than the draft of the vessel then capacity would, in fact, increase with a value of β greater

than three. There are two reasons that such a situation is reasonable. First, as the Corps of Engineers increases the depth of a channel they also tend to increase the radius of bends in the channel. If the radius of channel bends is increased more than in proportion to channel depth, then proportionately longer vessels can traverse channels of greater depth. Also, several of the vessels in our sample are Great Lakes ore carriers. These vessels tend to be quite long and limited only by structural integrity characteristics in Great Lakes storm conditions, rather than by the radius of channel bends. The second property of vessels which would increase their capacity as a function of draft is the changing proportion of vessel weight vs. cargo weight as draft increases. The volume and weight occupied by superstructure and running equipment need not increase as rapidly as the size of the vessel itself. (Supertankers are good examples of this. Relatively speaking, engine size and above water superstructure are quite small on such a vessel.) Thus, an increase in cargo capacity as a function of the fourth or fifth power of loaded draft is theoretically acceptable and perhaps even more reasonable than an increase with the third power.

In view of our indeterminate results, we tested our channel capacity proxy variable in the water-using air polluting industries employment (E_1) regression equation of our Chicago area spatial model for the above three integer powers. In terms of a priori expectations, our results improved consistently from the third to the fifth power.

In conclusion, both forms of regression model tested have certain undesirable patterns of the residuals. Arguments can be made in favor of either form. When the powers 3, 4, and 5 were tested in the regression of the spatial model, capacity as a function of channel depth to the fifth power gave best agreement with general a priori expectations. Consequently, the fifth power was selected for use in the final form of the model.

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Special thanks go to Ralph Braid who prepared the data base used in this study. Because of Ralph's conscientious efforts, this data base can be

recommended to our readers for its high quality. Problems certainly remain, but we doubt that any similar studies have had a higher quality data base to work with. Ralph was also a valuable critic of model structure and variable construction.

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