LOCATION-ALLOCATION MODEL EFFECTIVENESS
IN PUBLIC FACILITIES LOCATION

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PREFACE

This thesis investigates the influence of study area scale on computer location-allocation model effectiveness in the public sector problem. The ideas for this study developed from my work on projects for the Stillwater School System and Putnam City Schools.

Initially, I wish to thank all of the faculty and staff of the Geography department. Specifically, I would like to express unlimited gratitude to Dr. Stephen Tweedie for allowing me to participate in the Stillwater and Putnam City studies, and for providing outstanding and patient instruction during those "times that try mens souls." I was constantly amazed at his ability to create order from chaos, and feel blessed that I was able to work with and learn from such a competent man. I want to thank Professor James Stine for his continued interest and excellent assistance during my studies. He frequently developed ideas that would have remained dormant if not for his ability to synthesize new concepts. I would like to thank Dr. John Rooney Jr. for introducing me to the field of geography and for expressing confidence in my academic ability when others questioned my potential. Also, thanks, for his input and instruction during my

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CHAPTER I

INTRODUCTION

The understanding of the nature and operations of economic systems and the "space economy" is becoming more and more important , due to the increasing complexity of our modern economic systems. For decades geographers have been examining the spatial aspects of economic activity. One parameter of economic activity is location. Because the resource base, of raw materials or human resources, is not locationally homogeneous the task of organizing, and locationally allocating these resources in the most efficient manner becomes a paramount objective.

Much geographical research has resulted from this need for the optimal handling of mankind's resources. Numerous paradigms and theories have evolved to explain and describe the patterns and processes of market structure, retail structure, and industrial development. One area which has been given elaborate consideration and research is that of facilities location. Traditionally, location theorists strived to develop generalized "laws" to explain and evaluate facilites location. These laws and theories were centered around dollar profit and dollar costs as the main criteria for the selection of facility location. Central Place Theory and other location theories were based on purely economic components such as transport cost, market size, and price of the good to derive the solution to location problems, but ignored the influences of factors such as politics, etc. (Smith, 1971).

With the quantitative revolution, computer models emerged that greatly increased the geographer's ability to find the "optimal locational solution." As in previous work these models were built upon the premise of dollar profit and dollar cost as proper evaluative criteria for calculating the "optimal location" for any particular facility or set of facilities. But eventually the bubble was broken. Questions were raised concerning the ability of these models to correctly solve a problem that dealt with the location of publicly funded or operated facilities. The delivery of public goods introduces factors that were not considered in the traditional theories such as Central Place Theory. The actual price and market area of a good such as education is extremely hard to quantify, yet this would be necessary under the assumptions of the traditional location theories. Recognition of this fact brought about a need for a location theory that included these public good characteristics. At this point the birth of public facilities location theory was at hand.

This paper will document the existing research and current theories of public facilities location studies, and examine the impact of scale on public facilities locational analyses. Case studies of the Stillwater and Putnam City elementary schools will be analyzed with the aid of a spatial model, and the impact of scale upon the problem complexity and the model's effectiveness will be reviewed.

Spatial Models and the Location-Allocation Concept

Before exploring location-allocation and public facilities location models, the anatomy of spatial models in general should be examined.

Spatial Models

It has been stated by Chorley and Haggett (1967) that:

> A model can be a theory or a law or an hypothesis or a structured idea. It can be a role, a relocation or an equation. It can be a synthesis of data. Most important from the geographical viewpoint, it can also include reasoning about the real world by means of translations in space (to give spatial models) or in time (to give historical models) (pp. 21-22).

Models try to replicate, simulate, restructure, or explain conditions of reality. So one may conclude that models are abstractions of reality, and that a model's utility is evaluated on the basis of how efficiently and effectively a model represents the conditions of reality.

Chorley and Haggett (1967) outline six characteristics which all models should or do possess. They are:

1. INFORMATION SELECTIVITY- A fundamental feature of models is that inherently, necessary information must be selected and seperated from less important signals so that noise and insignificant information is excluded.

2. STRUCTURE- Models are structured so that the important characteristics of reality are exploited in terms of their interrelationships.

3. SUGGESTIVITY- A successful model encompasses suggestions for its own extension and generalizations.

4. APPROXIMATIONS- Models are only approximations of reality. They must be simple enough to be handled by the user, yet complex enough to accurately pattern the system under study.

5. ANALOGIES- Because models are different from reality they are analogs of reality.

6. REAPPLICABILITY- An effective and useful model should be able to be reapplied to the real world.

Apostel (1961) believes that models are necessary to develop a bridge between the observational and theoretical levels; and are concerned with simplification, reduction,concretization, experimentation, action, extension, globalization, theory formation and explanation. However, while models have enormous power (as Apostel suggest) one must not forget that the simulation of reality is a complex task and should be undertaken with great care and even moderate suspicion.

Spatial models in general assume that some degree of order in spatial behavior exists. Theoretically, spatial models strive to provide a system of order so that spatial behavior is organized in the most efficient manner possible. However, humans do not always behave in a rational manner and make decisions which would contribute to optimizing outcomes. Since this is true, one must assume that a certain amount of "error" in decision selection will occur and that a model based upon "best choice" decisions can never be truly implemented.

Morrill (1967) comments that the reasons for deviations from "Best-Model Choice" may be many. Each person may, in fact, behave in his most efficient manner , but what people interpret as cost differs from costs used in the model. Also important are multi-purpose trips, which may increase the distance one is willing to travel for one's purpose. Clearly, the modeling of human spatial behavior and organization is an incredibly complex, and to some degree, subjective task. For the purposes of this paper, it will be assumed that the study deals with a "rational" population and therefore the solutions generated do provide a decision set which would be adopted by the respective population.

The Location-Allocation Concept

Being a spatial model, location-allocation models attempt to calculate solutions that optimize a system's spatial organization and operation. In a general sense, the location-allocation problem has been defined as, " How shall we allocate one set of facilities to serve a second set of people?" (Abler, Adams, and Gould, 1971, p. 531). Cooper (1963), who published one of the first geographical articles directly addressing the location-allocation problem , defines the issue as examining (1) the location of each destination, (2) the requirements at each destination, (3) a set of shipping costs for a region of interest, and determining (1) the number of sources (sources being centers or entities which provide the good or service in demand), (2) the location of each source, and (3) the capacity of each source. Scott (1971) basically envisions the problem as an assignment of flows of a given commodity (or commodities) from producers to consumers so that the total cost of transportation within the system is minimized. This paper will conceptualize the problem as: Finding the optimal number, size, and location of centers to most efficiently supply a product or service to a spatially dispersed field of demand points, with a fixed or known demand, and optimally allocating the product or service demand among either new, relocated, or existing supply centers. In any case, the abundant definitions of what a location-allocation problem involves are consistent throughout the existing research. It should be noted that this consistency in general definitions should not be misunderstood to imply simplicity in the problem itself. Massam (1975) states that:

> In a general way it is easy to state the allocation-location problem, but when we try to apply it to specific services, for example, schools, hospitals, clinics, fire stations, or day care centers, under conditions which exist in particular places such as small municipalities, large metropolitian areas, or agricultural regions, both for the developed and developing world , then the general problem has to be restated to take local factors into account (p. 57).

Many cases in both the private and public sectors, where an exchange of a good or service takes place, inherently contain some form of a location-allocation system. The marketing concept involves the collection and organization of resources at the location of production facilities, the production of the good, and the allocation or transportation of the good to the consumer.

The basic concepts of location-allocation theory apply to both the public and private sectors in the same manner, yet the two problems diverge when analysts begin to address the "specific services" involved and the "local factors" that define the two types of problems.

Early work in location-allocation research did not differentiate a need for seperate consideration of public and private sector systems, and therefore, the analysis of public and private sector problems was approached with similiar methodology. After years of research, skepticism and inquiry began to surface about the effectiveness and ability of the existing methods and models to represent and synthesize the characteristics of the problem. This led to introspection and re-evaluation of the content of location-allocation problems in general, and in methods of modeling and analysis. This, in turn, paved the way for the divergence of public and private facilities location theory and for the conceptual "birth" of an seperate theory of public facilities location. The next section of this paper addresses the divergence of public from private sector location theories and the development of public location theory.

CHAPTER II

THE DIVERGENCE OF PUBLIC AND PRIVATE SECTOR LOCATION THEORIES

As research in location-allocation modelling progressed, it became clear that the current location-allocation models were powerful analytical tools, yet, the models lacked adequate considerations for dealing with public facilities problems, and in some instances private facilities location problems. The main questions were: what actually is the environment within which public and private facilities operate, and how do these two environments differ?

Differences Between the Public and Private Sector Environments

The most logical method of beginning a discussion of this type is to clarify and define what is a public facility, and what is a private facility. Teitz (1975, pp. 279) defines public facilities as, " components of the city whose primary function is to facilitate the provision of goods and services declared to be wholly or partly within the domain of government." This means a public facility is any which provides goods or services for public consumption and is funded completely or partially by either municipal, state, or federal expenditures. Examples include schools, hospitals, libraries, clinics, welfare offices, fire stations, police stations, parks, correctional facilities, and many others. A complete enumeration of the available examples is impractical but these examples indicate the large variety and importance of facilities that can be defined as "public."

A private facility can be defined as any facility which provide goods and services to the public either on a discriminate or indiscriminate basis, that is not funded by municipal, state, or federal government. Any privately owned or operated business is an example of a private facility.

It may appear that the dichotomous classification of these facilities makes analysis of the separate classes simple. In practice this simple dissection is not so straightforward when trying to evaluate and characterize the organizational and operational environments of the two classes. An analysis of both sectors must consider the "spillover" and interdependant relationships which permeate both environments.

Numerous discussions have been devoted to identifying the contrast and comparisions between the public and private economic environments. In general, most authors agree upon the various features that differentiate the public and private sector problems. The literature suggest eleven attributes which explain the distinction between the two environments. These eleven attributes can be summarized and identified in the following manner:

ECONOMIC ATTRIBUTES

1. Demand
2. Pricing Systems
3. Facilities Viability
4. Agglomerative Tendencies

INSTITUTIONAL ATTRIBUTES

1. Jurisdictional Structure
2. Political Content
3. Conflict Potential
4. Linkage
5. Hiearchical Nature

INTERACTIONAL ATTRIBUTES

1. Expenditures Determination
2. Evaluative Methodology

Economic Attributes

This particular group of attributes were classed as economic attributes because they all appear to be financial in essence. Each will be discussed and elaborated upon to identify the public -private similiarities or differences within each attribute.

Demand. The difficulty in determining demand for a public good is addressed by many authors (Dear, 1975; Lea, 1979; Massam, 1975; Revelle, Marks, and Liebman, 1970; Tietz, 1975). Dear (1975) describes the "notion" of public goods demand as particulary "fuzzy" and says that it is more appropriate to speak of "need" which is something quite different and much less measurable. Questions such as, "What is the demand for education, and can, or how this be quantified?" are frequently asked. Clearly, the intangibility and subjectivity of defining a "public good" inhibits the ease of calculating and assessing demand. In the private sector the existence and identification of a good is much easier to define. Since a dollar cost is usually associated with a private good, and given the traditional economic theory of demand as a function of price, then demand is naturally easier to quantify and predict.

Pricing Systems. As mentioned above, the intangibility and subjectivity of what a public good actually is , and the corresponding price, forms a barrier to calculating demand. This inability to calculate a quantifiable price also brings about an absence of a price structure and a competitive pricing system for public sector goods, as documented by Tietz (1975). In the private sector, almost all goods possess a quantifiable price, and therefore, price competition is inherent. It is hard to calculate a least-cost location for a public facility when the cost associated with it's use cannot be precisely defined.

Facilities Viability. A facility's viability, or survival, usually depends upon how profitable or efficient the facility is at obtaining the desired objective at hand. Due to the lack of public sector evaluative criteria, which will be elaborated upon later, , critical evaluation of the performance and effectiveness of a public facility is quite difficult. The combination of no competitiveness, and a lack of evaluative methods, allows the survival of inefficient public facilities that would have otherwise been forced into bankruptcy in the private sector. In a free enterprise economy, the competitive environment of the private sector and the existence of evaluative criteria, prohibits survival of most firms that are not profitable, therefore insuring continued quality and integrity in the private environment.

Agglomerative Tendencies. This attribute is one where the differences between the private and public sectors are less evident. The agglomerative, or lack of agglomerative, tendencies in the public sector depends upon the particular type of service being discussed. It appears that facililties with definite service regions, such as schools, have no agglomerative tendencies while facilities that have indefinite service regions ,such as medical facilities, tend to agglomerate. In addition, the reduction of costs to public facilities by agglomeration would most likely be less than the economies seen in the private sector. It is well known that agglomeration in the private sector is widespread, but the degree depends, in part, upon the particular good, service, or industry under discussion. For instance, research and development firms and the microchip industry display high agglomeration. In contrast, sporting goods manufacturing and the meat packing industry provides examples of spatially dispersed industries.

Institutional Attributes

The following group of attributes were classed as institutional because the attributes tended to arise from the type of organizational structure that the facility, or set of facilities, displayed. As before, each attribute will be discussed in an effort to identify the public-private similiarities or differences within each attribute.

Jurisdictional Structure. The public facility is controlled by the public jurisdictional/administrative unit within which it exists and serves. The decisions concerning the development, location, size, expenditures, objectives, and sucessfulness, of public facilities are made by individuals who are either publicly elected or supported. Ideally, the decisions are designed to reflect the intentions and desires of the public, and attempt to provide equity of service among the public. Public facilities may be "nested" within several jurisdictional/administrative units, such as a project funded at both the state and federal level. The nature of a "nested" project makes political or decisional conflict probable, as in any system where politics are involved (Dear, 1975). Public facility systems usually make "centralized" policy decisions that apply to the total system, therefore, a decision may be optimal for the system, yet, provide a suboptimal choice for an individual facility.

The private sector, although partially accountable to governmental regulations and to public sentiment, does <u>not</u> have to make decisions which provide equitable service among the public. Decisions are usually made according to the consideration of profitablility. Though a private facility may be "nested" within several administrative entities, the goals of each unit are more unified towards the overall goal of producing profits. Due to the "decentralized" nature of the organizational decision processes of the private firm, facilities may obtain better operational decisions on an individual basis.

Political Content. While any organizational structure contains a certain amount of political content, the public goods sector is highly politicized. The locational and operational decisions concerning public facilities are clearly acts of political nature that represent a compromise between a set of conflicting choices. Dear (1975) states that:

> Traditional efficiency considerations are also important (such as the minimum operating size of a fire station) but these are of secondary significance. First, the almost complete lack of criteria for locating public facilities virtually guarantees that the locational decision becomes the object of unbalanced political pressures. Second, the imperfect mechanisms of information diffusion and the translation of political goals into operational objectives for location, further unbalance political decision making (p. 290).

Dear is not the only author to recognize this. Wolpert (1970) states that:

> Sometimes the location finally chosen for a new development, or the site chosen for a relocaton of an existing facility, comes out to be the site around which the least protest can be generated by those to be displaced. Rather than being an optimal, a rational, or even a satisfactory locational decision produced by the resolution of conflicting judgements, the decision is perhaps merely the expression of rejection by elements powerful enough to enforce their decision that another location must not be used (p. 220).

The private sector, although operating under evident political considerations, does not necessarily make decisions that are equitable, and publicly defendable. The recent exposure of poor chemical waste disposal practices clearly illustrates management decisions that do not benefit the "public welfare."

The nature of the public good makes the good a political one, which allows it to be used as a weapon for or against political entities or individuals. This political attribute has undoubtably brought about the siting of public facilities in locations which were not economically cost minimizing. Clearly, one cannot ignore the influence that politics has upon the operations of society, nor expect the seperation of political ideas from decision criteria. Although, many public locational theorist have addressed the infinite problems that the political factor infuses into the public sector locational problem, proper treatment of political influences and its effect upon public facilities locational modelling has yet to be refined.

Conflict Potential. The potential for conflict in the public sector is very high in comparision to the private sector. The nature of the problem and the processes behind decision selection create an environment in which conflict is probable. Dear (1975) states that:

> The problem is characterized by the multiplicity of inputs to a locational decision: diverse groups interact, bringing differing motivations and goals to the decision-making process. Not suprisingly, conflict is inherent. Conflict can also be generated in situations where consumers lack alternatives in the private sector and cannot cease consumption of one output in favor of another (p. 288).

The "publicness" of information and the politicial flavor of public sector decisions contributes to a greater potential for conflict than in the private sector.

Linkage. The need for consideration of a "systems" approach to locational problems has been previously voiced by many economic geographers, and should apply to both the public and private sectors. Public facilities location usually deals with the siting of individual, or several, facilities to be integrated into an already existing system of facilities. Tietz (1975, p. 283) comments that, "The effectiveness of the system as a whole depends upon the scale of its components and their combined relationships to each other." This emphasizes the point that the locational analyst must consider the public service system as an integrated unit, and must consider not only the existing facilities location, but size as well. In cases where inefficient public facilities are, in some sense, "subsidized" or supported by more efficient facilities, the recognition of locational interdependencies is crucial (White, 1979). Since, in a free enterprise economy, the private sector analyst usually locates a individual facility, the need for examination of linkages is much less, but still necessary.

Hierarchical Nature. Public facility systems almost always display some form of hierarchical properties. Dear cites hierarchical tendencies as one of three characteristics common to public facility location problems. He suggests that the hierarchy may manifest itself in terms of capacities (one large central library, and several smaller branch libraries) or in terms of organizational structure (as in a typical hospitialization sequence of intake-treatment-convalescence-release), (Dear, 1975). Tietz (1975) also cites hierarchal properties as a characteristic of public facilities. Sewer and water pipe networks contain steplike attenuation in capacity from the households to the sewage treatment plant. Public school systems contain hiearchies in that numerous elementary schools feed children into fewer middle or junior high schools, which then, feed students into even fewer high schools. Therefore, when locating new school facilities or allocating students within an existing system, one must consider how this will impact the other levels of the hierarchy. The hierarchical nature of public facilities supports the premise that interdependencies and linkages <u>must</u> be examined when making locational or allocational studies.

The private sector location problem must also deal with interdependencies and hierarchical structure. The fact that a location problem in the private sector usually only involves the siting of a single facility relieves some of the burden of examining and considering this attribute, yet the need for treatment of this factor in the private sector is crucial to the overall problem.

Interactional Attributes

The two attributes, expenditure determination and evaluative methodology, were included in a separate class because of their nature. These attributes result from the interaction of the economic conditions characteristic to the public sector environment and the institutional characteristics of public facilities.

Expenditure Determination. Public sector service systems involve public revenues and expenditures which must be accountable to the public. Therefore, the type of organizational structure of public systems greatly impacts the methods by which the system expenditures are determined. Tietz has outlined the general methods through which public expenditures are decided.

Society dictates what part of its resources will be allocated to what objectives. Government allocates resources to major program areas which are clusters of objectives of a similiar type (such as education). Major programs allocate to particular programs (such as subsidized school lunch programs). Particular programs allocate to specific facilities (federal or state government payments to specific school districts). Specific facilities allocate service to society (specific schools provide subsidized lunches to students) (Tietz, 1975).

Compared with private sector decisions, this process clearly involves many political entities and mechanisms which increase the potential for conflict. Since society is composed of many different "groups", each with their own goals and objectives, the public decision-maker must weigh these goals and objectives and select the direction of particular programs. The decision should provide maximum equity and welfare for society, but the subjectivity and difficulty in measuring "what is good for society" is tremendous. In addition, decisions concerning publicly provided services need to provide not only equity, but also efficiency, and must be publicly defendable.

From an economic viewpoint, the amount of public expenditure is limited to the tax base potential of the corresponding jurisdictional/administrative unit. Operating funds are not directly provided by the consumer at the point of consumption, because the consumer does not "purchase" the product in a conventional style. By contrast, in the private sector, the amount of expenditure does not reflect the size of the jurisdictional unit, but the size of the market captured by the facilities or firm. Operating funds are directly provided by the consumer at the point of purchase of the good or services. The "decision set" which determines private facilities expenditures is not a public decision, and is not required to consider the benefit or welfare of the public as a decision input.

Evaluative Methodology. Public facilities provide a good which has no determinable price and a nonquantifiable demand, making it difficult to evaluate, in dollar or nondollar terminology, the cost and benefit to the system that a facility provides. This inherent vagueness in definition introduces tremendous subjectivity into the process of evaluating the effectiveness of any public facility. The difficulty in measuring social costs and benefits for a public facility has been reviewed by many researchers, with limited success (Dear, 1975; Harvey, 1975; Lea, 1979; Massam, 1975; Revelle, Marks, and Liebman, 1970; Tietz, 1975; Wagner and Falkson, 1975; and White, 1979).

The extremely puzzling task of defining what is best for society allows a freedom in measuring objectives and performance which the private sector does not possess. As mentioned earlier, a public facility may be operating inefficiently, yet survive, whereas in the private sector, such a facility would be forced into bankruptcy. In the private sector, a firm can easily be evaluated upon dollar costs incurred, and dollar profit generated, so that the success (or failure) of a facility may be easily determined.

The preceding discussion demonstrates that the differences between the public and private sectors are extensive, and suggests some of the characteristics of a public facility paradigm in locational analysis. It is evident that a single theory for facilities location cannot adequately represent both types.

The Origin and Development of Public Facilities Location Theory

Recognition of the need for a different theory for public facilities locational analysis was first formalized in Tietz's (1975) article, " Towards a Theory of Public Facility Location." This article was the pioneering step that directly stated a need for an individual location theory for public facilities. In this work the characteristics of public goods and public facilities was investigated, and an efficiency oriented expenditures equilibrium approach was developed. Tietz's article first published in 1968 and reprinted in 1975, paved the road for further research in the public sector environment.

The literature in public facilities location has been mainly either theoretical or technical in nature (Lea, 1979). The theoretical work commonly pursues the concepts and characteristics of the public sector problem. Variables such as the political, jurisdictional, and expenditures factors are the topics of much of this work (Cox, 1979; Dear, 1975; Bigman and Revelle, 1978; Harvey, 1975; Lea, 1979; Morrill and Symons, 1977; Massam, 1975; Smolensky, Burton, and Tideman, 1970; Tietz, 1975; White, 1979; Wolch, 1979). The technical work revolves around the creation and perfection of algorithmic models (Lea, 1979; Khumawala, 1972; Kolesar and Walker, 1974; Revelle and Swain, 1970; Rojeski and Revelle, 1970; Toregas, Swain, Revelle, and Bergman, 1971). The theoretical and technical research cannot totally be separated, and in fact much of the work possesses both theoretical and technical characteristics.

The majority of theoretical background was developed in articles by Tietz (1975); Revelle, Marks, and Liebman (1970); and Dear (1975). The remainder of the research, which consists of a large amount of work, examines the "fine tuning" of the socio-economic attributes in the models, and the corresponding adjustments of certain constraints and parameters in the algorithms.

The eleven attributes identified and discussed in this chapter are drawn from this literature and provide a summation of the nontechnical content of most articles. A detailed discussion of individual articles would be largely redundant. A technical discussion of the algorithms most frequently used in location-allocation models was considered unnecessary for the purposes of this thesis. A fine introductory analysis of basic location-allocation concepts and algorithmic procedures is provided in Allen Scott's resource paper "An Introduction to Spatial Allocation Analysis." The next portion of this study will address the impact of scale upon public facilities location problems.

CHAPTER III

THE IMPACT OF SCALE ON PUBLIC FACILITIES LOCATION

The Scale Classes

The public facilities location problem is complicated by many factors other than the eleven attributes that were outlined in the previous chapter. Since man and society frequently behave irrationally, the public facilities location-allocation problem is compounded by the dysfunctional "quirks" of society that often frustrate attempts to systematically order human spatial behavior.

Public service systems are designed to serve a specific "market" of consumers that are contained within the system's jurisdiction. This "market" or "target population", is composed of a sociologically interactive and heterogenous population, which should be examined when conducting studies of public facilities location.

The identification and location of this target population is directly related to the scale of the "social ecology" of the area under consideration and leads to questions related to the scale of the location problem.

This comment reiterates Massam's statement concerning the general location-allocation concept, and the consideration of local factors when examining specific services. He cites the need for addressing individual conditions at varying problem scales; the small municipality, the metropolitan area, and the agricultural region, (Massam, 1975). The term scale in this study is not used in the traditional sense to refer to map size and or representative fraction, but to define the size of the problem, i.e., population size, etc.

An analysis of the public school systems of New York City would be markedly different from that of Stillwater, Oklahoma. Massam (1975) states that:

> Attempts can be made to search for relationships between the spatial properties of administrative areas and the other attributes, specifically those concerning the function of the unit (p. 4).

This implies that the scale or size of an administrative unit "conditions" the activities that are contained within. One may assume that the "nesting" of functions, much as the higher and lower order centers of Christaller's model, occurs in the delivery of public goods. A city such as Dallas, Texas, would contain a broader "hierarchy" of public goods than the city of Carney, Oklahoma.

As discussed earlier, the scale of the administrative unit directly affects the public sector expenditures budget, therefore directly affecting the supply of public goods. If size or scale exhibits such an influential bearing upon the demand and supply of public goods, then the impact of this factor upon public facilities location theory should be examined. This section explores the various attributes of public facilities location problems at different scales.

The size or scale of the "target" market at which services are directed affects the composition of the market and consequently the nature of the locational problem. For the purposes of this study, three classes of scale will be developed as follows:

A. SMALL SCALE
   1. Rural
   2. Nonmetropolitian

B. INTERMEDIATE SCALE
   1. Metropolitian
   2. Regional

C. LARGE SCALE
   1. Multi-regional
   2. National

Again, it should be noted, that the term study scale is not limited to areal size.

The small scale class will include rural areas, unincorporated areas, villages, hamlets, towns, and nonmetropolition cities. This class can flexibly be stated as dealing with populations of less than 50,000. All items included possess similiar characteristics and environments, therefore, lending themselves to analysis with generally identicial techniques. Incidentally, the fact that these problems were identified as "small" does not imply that these problems are simple. The considerations and constraints, although usually less complex than those of the intermediate and large scale, are numerous enough to provide ample challenge for any researcher. In this thesis, the Stillwater School System will be analyzed at the elementary level, therefore providing a small scale example.

The intermediate class will include metropolitian areas and regions. Metropolitian areas, as defined by the U. S. Census Bureau, consist of a city (or two contiguious cities) with a population greater than 50,000. The definition of a region is somewhat more subjective. In general, a region might be defined as some cohesive spatial unit. This may consists of parts of a state, a state itself, or several states. In the context of this study the important aspect is that the concept of a region is based upon an interdependent and interactive relationship. An example of the intermediate scale problem will be reviewed in the analysis of the Putnam City Elementary Schools.

The large scale class includes multi-regional and national spatial units. The multi-regional unit is comprised of several regions, and given the subjectiveness of defining a "region", the same subjectivity is evident in precisely defining the multi-regional entity. A nation can be defined as a spatial unit under the administration or jurisdiction of a single political body. A discussion of the regional districts of the Internal Revenue Service will review one example of a large scale problem.

Clearly, "gray areas" exist between the three scales and the corresponding components. Scales involved in actual problems form a continuum; no clear delineation of the three classes can be achieved. This concept could be portrayed as a graph with the small scale on one end, large scale on the other, and an infinite number of points in between.

The Critical Scale Components

From the inspection of publicly oriented location-allocation research, five crucial scale components emerged. They are:

1. The physical aspects of the study area.
2. The number of actual and perceptual sub-units.
3. The population behavior.
4. The ecologicial organization.
5. The jurisdictional/administrative organization.

The five components listed above will be discussed in terms of the variations within each type from scale to scale in order to emphasize the point that study area scale greatly affects the environments within which a locational decision is calculated and implemented.

The Physical Aspects of the Area

The physical scale of the study area will naturally have a strong impact on the inputs and solutions of the public facilities locational problem. Distances, and the study area population will both be a function of the unit size. The distance component is influential due to the distance decay concept. The farther a consumer is from a facility, the less likely the consumer is to patronize the facility (Wagner and Falkson, 1975). When considering the delivery of emergency services, distance takes on a temporal character. The minimization of time (as a function of distance) to the most distant consumer is the ultimate objective (McClendon, Oehrtman, and Doeksen, 1978). In the siting of facilities such as schools, the population usually desires close proximity to the facility. On the other hand, the population usually desires the maximum possible "detachment" from noxious facilities, such as a waste disposal site.

Distance contains two important aspects that are of concern to the spatial analyst. Distance inherently contains a cost component. To move either a population to a good or service, or a good or service to the population, requires inputs that incur some form of cost. In the public sector, this cost may be hard to define, but it still exists.

Distance also portrays an element of accessibility. The closer a facility is to the consumer the more accessible it becomes, while greater distance implies lesser accessibility. Several authors have researched accessibility as the major consideration in the public locational problem, (White, 1979; McLafferty, 1982).

Finally, most algorithmicaly based spatial analysis utilize distance as the measure to be minimized when calculating the solution. So the importance of distance is paramount to locational analysis of this type.

Also, the size of the study area usually influences the size of the target population. In general, the larger the population, the more complex the calculation of an equitable and efficient solution. A large population usually contains greater internal demographic and political variation, therefore increasing the potential for functional conflict (Morrill, 1973). Although, in some cases the sheer numbers involved tend to "average out" minor demographic and political variations and thus reduce the difficulties. In addition, overwhemingly large data sets increase the probability of error.

Another influential physical characteristic which must be attended to is the land use pattern of the study area. Since society does not exist upon a "homogenous surface" then the diverse conditions that man has imposed upon the Earth affects the "mechanisms" of society's functions.

Transportation is limited to the networks that make movement possible. Automobiles must follow roads, so the possibilities of movement and interchange are predestined by the network upon which it travels. The small and intermediate scaled problems are particularily influenced by land use patterns. It is impossible to construct a six lane highway through a quiet residential area without propagating massive citizen resistance. In the urban environment, development may not be contigious. Gaps may "isolate" areas which then limit the choices of delivery of a public good, (Tweedie and Pooler, 1983). This phenomenon contributes to the selection and implementation of strategies which are less than optimal. Unfortunately, urban planners cannot determine development in order to implement an optimal spatial arrangement.

The effects of construction of a public facility upon the surrounding land values and use patterns is another impact of public facilities worth examining. Dear (1975) addresses this in his statement:

> One is forced to conceptualize public facilities as primary generators of land use change, including private sector responses to the public sector development. In short, new public facililty paradigms would need to incorporate some sort of 'planning' consciousness (p. 286).

Public facilities may act as "growth catalysts" for private development. The "spinoffs" of the siting of public facilities upon the urban landscape are an important consideration that urban planners may, and should, use as a planning aid. Tietz (1975) indicates that:

> If government can use public facilities as instruments to shape urban growth and social and economic behavior, then a new level of evaluation is superimposed on the usual considerations for public services (p. 278).

In a large scale problem, the importance of land use patterns is probably less that at the other two scales. When dealing with a multi-regional or national scale problem, such as the Internal Revenue Service regional structure, the small variations are "smoothed out." Only the very generalized patterns are evident. This does not mean that land use patterns are not influential, but less so than at the small or intermediate scale.

The final element of the physical aspects is physical geography. Many natural barriers exist that inhibit transportation. Rivers, bays, mountains, canyons, and numerous other phenomena "shape" the possibilities of travel. Physical barriers provided difficulities for Morrill (1973) when he attempted a political redistricting of Washington. He states that:

> At times natural environmental criteria are invoked- for example, districts should not cross physical barriers like bays or estuaries, large lakes or mountain ranges (p. 466).

San Francisco, California, provides a fine example of the impact that the physical landscape has upon the urban area. On a national scale, the Rocky Mountains limit transportation routes, therefore influencing commerce and development.

In summary, the physical characteristics of a study area greatly effect the composition of the location-allocation problem, and must be given ample consideration.

Number of Sub-units

The "natural" sub-units contained within a study area also influence the problem. Sub-units can be neighborhoods, municipalities, cities, states, or regions. The size and type of sub-unit depends upon the scale of the problem under consideration. Each problem has it's own "natural" subdivisions.

Sub-units are often defined in the context of the current service areas of the established facilities system. For example, when examining school locations and districts, the existing school districts determine many of the unit boundaries. And, since within a district elementary schools feed junior-high schools, which supply high schools, the examination of the sub-units at each "level" is mandatory, (Tweedie and Pooler, 1983). For a private sector firm, a "natural" unit may consist of existing sales regions or service areas. At the large scale, a sub-unit may be a state or a number of states. These sub-units may each contain highly variable populations and environments. Because states are individual political units, conflict could result from different policies and legislations that each state enacts. Given the hierarchical nature of public service systems, consideration of the study area's sub-units is necessary.

Population Behavior

Location-allocation models in attempting to optimally "order" a population's spatial behavior, must therefore identify the interaction patterns and processes of the study area population.

White (1979, p. 19) states, "The utilization of public services can therefore be treated as a problem of spatial interaction." Massam, in agreement with White, encourages recognition of the interactive processes which occur in the public sector. Clearly, the environment in which the locational analyst works is dynamic, therefore affecting the "local factors" which Massam considers so influential, (Massam, 1975).

The amount of anticipated population growth within a study area is one behavioral aspect of great importance. The siting of a public facility usually incurs significant long-term capital outlay. To make this outlay most effective over time, prediction of the future needs and development of an area is important. In general, small scale problems contain environments where prediction of growth is easy and accurate, over the short run of time. The large scale problems, although, more complicated than the small scale, are also handled without enormous difficulty. The size of the problem allows the inspection of "trends" and small variations are "averaged out" by sheer numbers. The intermediate scale problem appears to provide the most difficulty in growth prediction. This scale produces a problem that is large enough to inhibit the practical collection of detailed data, yet small enough that the variations cannot be smoothed out.

The distribution of growth within an intermediate scale problem further complicates the situation. Parts of a specific study area may exhibit "high growth" while others have little or no growth. High growth areas usually attract new public facilities, therefore possibly developing a belief among slow growth area consumers that inequitable treatment is occurring. This in turn, increases the chances for political conflict. The larger the scale of the study area, the higher the probability that uneven growth will occur, and that conflict will arise.

The mobility of the study area population also influences the location-allocation problem. A highly mobile population complicates growth and population prediction, and contributes to data obsolescence. The small scale study areas, such as Stillwater, Oklahoma, usually experience a reasonable amount of internal migration (inner city movements), and "stable replacement" external migration. The term "stable replacement" implies that population movements into the study area "counterbalance" the population movements out of the study area, therefore creating a stable population base, (Tweedie and Pooler, 1983). The problem of assessing population movement on a large scale is simplified by the greater availability of state or national level data. The sheer numbers of the population makes small movements insignificant. However, at the intermediate scale, analysis of population change is compounded by the lack of reputable data on intra-metropolitian or intra-state movements. These movements are small enough that accurate data is hard to obtain, yet large enough that they are significant.

The Ecological Organization

The size of the study area governs the general characteristics of its demographic composition or "social ecology" which in turn influences the solution to the location-allocation problem. The small scale study area, such as Stillwater, Oklahoma generally contains a population that is minutely stratified. Although demographic stratification exist, the effects upon the "mechanisms" of the unit are lessened because the small size forces the social integration of all "levels", especially when the population is consuming public goods.

Public facilities do not exist which serve demographically "pure" neighborhoods or "pure" populations. The Stillwater School System provides a good example. All children, either from low or high income areas, attend the same middle, junior and senior high schools, thereby forcing the social interaction of different social classes. Areal size ensures that each "sub-unit" enjoys reasonable accessibility to every facility, promoting an equitable delivery of public goods. This provides a "unified" public sentiment, and reduces the chances for conflict.

The intermediate scale problem contains a totally different set of social characteristics. The population is much more stratified than the small scale population. The different "social strata" are effectively segregrated when consuming public goods, because of the large distances involved. At the small scale, each "sub-unit" experiences high accessibility to all public facilities. The population in the intermediate scale problem does <u>not</u> enjoy high accessibility because large distances inhibit the use of certain facilities.

The fact that intermediate scale population sub-units are spatially segregrated reduces total cohesiveness and increases the chances for conflict. The larger size of the intermediate population ensures greater internal ethnic and racial variation, increasing the complexity of the problem. In a study by Hall, the optimal redistricting of the Chicago Public Schools was complicated by the need for racial integration and racial balance, (Hall, 1973). The sociological composition of the population suggests "natural districts" and "natural data units." Morrill (1973) supports this in his comments:

> Districts should be more than arbitrary geometric collections of people, and should possess some unity or meaning in the eyes of the residents. A practical procedure is to attempt to delimit districts which at the same time have some <u>functional cohesion</u> and <u>uniformity of character</u>. Perhaps a functional criterion might be possible in rural areas, where nodal regions are somewhat more sharply defined, whereas cultural homogeneity would be more important in metropolitan areas, where nodal regions are much less precise (pp. 466-467).

Morrill's comment supports both the importance of inspection of sociological characteristics, as well as the premise that scale impacts the scope and analytical techniques of the problem. The data should best reflect the "natural districts" in a study area, so that the conclusions derived will not only provide a fine technical solution, but one that can be implemented in the "real world."

The large scale problem, like the others, must consider the sociological organization to provide an accurate solution. The size of the problem makes this constraint easier to work with, because of the "averaging out" effect mentioned previously. The ethnic and racial variations are homogenized, and the detection of "natural districts" and data units is simplified.

In the large scale problem, the majority of the population has poor accessibility to the facilities. Despite the possibility that some groups are obtaining better service than others, the chances for political conflict are lessened, perhaps because at this level people are more likely to be resigned to poor, impersonal service dictated by outsiders. In general, the ecological organization of the large scale problem should not be viewed as "simple" or "insignificant", but the difficulties in handling this factor are lesser at the large and small scales than at the intermediate level.

The Jurisdictional Organization

Public facilities rely upon the jurisdictional unit within which they operate as their source of funds, and their budget depends upon the tax base potential of that unit. In general, the larger the jurisdictional boundaries, the larger the amount of funds available for public goods delivery.

Public facilities may be "nested" within many jurisdictional or political entities. In the rural area or nonmetropolitan community, public facilities are usually controlled by the city or county governments. In the metropolitan area or region, the jurisdiction may fall under numerous city, municipal, and state governments. At the large scale, many metropolitan, state, and even federal jurisdictions will apply. The number of hiearchical "levels" contained within a public goods system, definitely affects the problem scope.

At the small scale, the jurisdictional hierarchy is clearly defined, therefore generating little competition and lessened chances for conflict. In the intermediate size problem, the hierarchy is complicated by numerous "political entities" that compete for resources within the organization. This provides an environment that encourages competition, and therefore, produces conflict. In addition, complexities in information exchange between jurisdictional units may arise. In the delivery of firefighting services, no "gaps" in service or information transfer can exist without the loss of life, yet the political fragmentation of a city often frustrates efforts to coordinate all firefighting units in the area.

The large scale problem contains numerous entities and high potential for conflict and competition. However, the intervention of the federal government provides a "final policy" maker which directs the conflicting political units towards a unified goal.

Clearly, one can see that the problems and complications in a locational-allocational analysis are affected by the scale of the jurisdictional organization, which unquestionably, results in the implementation of nonoptimal decisions. By realizing the impact of the jurisdictional organization upon the public goods system, the researcher may generate a better technical and applicable solution.

Many researchers have implicitly addressed the impact of scale upon location-allocation problems (Dear, 1975; Massam, 1975; Morrill, 1973; Tietz, 1975), but none have directly identified the scale components in this thesis. While specific examples may be found which question the validity of some statements, the general concepts concerning the five scale components can be defended.

The preceeding discussion suggests that the locational analyst may find the greatest difficulties when researching problems of the intermediate scale. This should not imply that the small and large scale problems are simple, but that generally, the five scale components are most complex at the intermediate level. This concept can be represented graphically as shown in Figure 1.

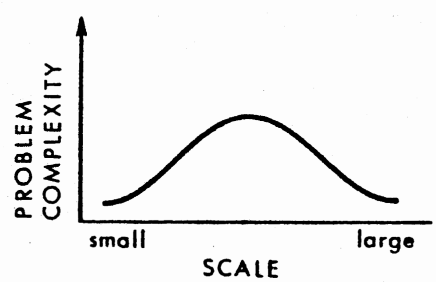

Figure 1. The Impact of Scale on Problem Complexity

The next chapter presents three examples which illustrate the influence of scale on problem complexity and model effectiveness.

CHAPTER IV

CASE STUDIES IN THE LOCATION-ALLOCATION OF PUBLIC FACILITIES

The preceding portion of this thesis reviewed the theoretical aspects of public locational problems and the impact of scale upon these problems. This chapter displays the general techniques and characteristics of location-allocation modelling, provides two analyses of small and intermediate scale location-allocation problems, discusses one example of a large scale problem, and inspects the influence of scale upon model effectiveness and conclusions for the case studies.

General Model Techniques

Input Data Structure

As mentioned previously, the data and data structure that is used in modelling techniques greatly determines the validity of the model solution, and therefore, is an important aspect of the analysis. The data that is analyzed when executing a location-allocation analyis consist of the consumers of the particular good or service, and their locations in space. Computer models require the user to develop a spatial X-Y coordinate system that represents the "population surface". The data must be aggregrated into "data units", since it is impractical to use individual consumers. The process of identifying the "data units" can be a difficult and trying task. Data units should reflect the "natural" units of the target population. Morrill (1973) recommends that data units possess similiar characteristics and not be simply "geometric collections of people." The scale of the problem directly influences the methods that should be used in aggregating and organizing the data. This point will be highlighted in the review of the two case studies.

Each data unit and service facility is assigned a numerical X-Y coordinate. The facilities may be capacitated to limit the maximum number of consumers allocated to any specific center (corresponding to building capacity, etc.) and be either fixed or mobile in location. This allows the development of a "cost surface", based upon the spatial distance from consumers to facility, and the measurement and minimization of transportation "cost".

The Objective Function

The objective function is the algebraic expression which determines the manner in which the computer routine measures costs. Various programs contain different measurements of cost in the objective function. Some programs utilize an objective function designed to minimize the total transportation distance, (Goodchild, 1973). Programs that analyze the delivery of emergency services contain objective functions that minimize the maximum distance to the most distant consumer, or minimize the average total response time, (McClendon, Oehrtman, and Doeksen, 1978). In this context, distance takes on a temporal characteristic, and time is incorporated into the objective function as a parameter to be minimized.

Private sector location-allocation models may incorporate many different constraints and objective functions. In Flynn's work, an algorithm was designed to allocate the transport of high and low sulphur coals to power plants with larger and smaller desulphurization capacities, (Flynn, 1982). A model developed by Osleeb and Cromley utilized an algorithm that operated on a uniform delivered pricing structure, therefore better replicating the economic conditions of the soft drink bottling industry, (Osleeb and Cromley, 1978). Many different examples of "hybrid" algorithimic models exist, yet all are based upon the minimization or maximization of various parameters within the objective function.

Output

The output of location-allocation models consist of the assignments of the data units to the various facilities. The facilities, if allowed to relocate, are moved to the least-cost location (stated in X-Y coordinates), and the data units are allocated according to capacity constraints, if any. Occasionally, data units may be split so that capacity constraints (such as building capacity) can be met or a least-cost solution derived. When a data unit is split by the program, the population within the data unit must be redefined at a finer level for the researcher to effectively divide the data unit. The program calculates a cost figure that is stated in units of the X-Y grid. This distance measure is calculated as if each consumer of the service travelled seperately. When applied to a school district the actual transport cost is much lower, since a school bus can carry approximately 50 children, but this distance measure can be used as a guide for comparative assessment of the efficiency of various computer solutions.

The previous discussion outlines the general model techniques of most location-allocation models. The next section will examine two case studies that utilized a location-allocation program to redistrict the elementary level catchment areas of Stillwater and Putnam City School Systems. The Stillwater and Putnam City examples are analyzed as single units, and the Putnam City study is additionally broken down into "sub-units" and analyzed at the dis-aggregrate level. This is done in order to compare the utility of the model at the aggregate and dis-aggregate levels.

The regional district structure of the Internal Revenue Service will be reviewed to examine a large scale example. This example will not be analyzed in the same manner as Stillwater and Putnam City Schools, but will be discussed so that investigation of the impact of scale on a large scale problem can be inspected.

Example I: Stillwater Elementary Schools

Background

Stillwater, Oklahoma, located roughly 65 miles northeast of Oklahoma City, is a community of approximately 42,000 people and 16,640 acres within the city limits. It hosts the County seat of Payne County, and the main campus of Oklahoma State University, with a student population of greater than 22,000, is located in the center of town. Due to the university, a large portion of the population migrates to and from the city annually. The Stillwater School District contains five elementary schools (grades K-5), one middle school (grades 6-7), one junior high (grades 8-9), and one high school (grades 10-12), and educates approximately 4000 students. The capacities of the five elementary schools range from 350 students to 455.

Goals of the Analysis

The goals of this analysis are to delimit school catchment areas, in an optimal manner, for the five elementary schools of the Stillwater Public School System, and to examine the impact of scale upon the problem content and model efficiency. This study will not involve the relocation of facilities or the locating of new facilities, but will only be directed towards the development of attendance zones for the five existing schools. Since this case study is used to illustrate specific points, only the current population base is used. Ideally, population projections should be developed so that the solution will prove most effective over time. This analysis will be executed with the aid of the Location-Allocation Package, an algorithmic distance minimizing location-allocation model written by Goodchild (1973).

Data and Data Units

The data base for this study consist of the elementary age student population as listed in the Stillwater School enrollment records as of March, 1982. The data was aggregrated into 106 units that correspond with the Stillwater traffic demand zones (TDZ's) identified by the City of Stillwater as basic mapping and administrative zones. Some rural children did not live within the boundaries of any of the TDZ's and as addressed by Tweedie in the Stillwater Density Study,

> The boundaries of the Stillwater School District are not used by the U. S. Census in delimiting population enumeration districts in the area surrounding the City of Stillwater. Since these rural enumeration districts contain large areas that are served by other school districts, the U. S. Census of Population cannot be used to estimate the population in the rural parts of the school district, (Tweedie, 1982, p. 1).

In the actual Stillwater study, the rural population was assigned to the nearest Traffic Demand Zone. For the purposes of this study, the rural population (accounting for about 5% of the school enrollments) was not considered. The study area and data units are shown in Figure 2.

Figure 2 shows that the data units are smaller in the center of the city. This allows the computer model to make "fine tuning" allocations and helps prevent the allocational "spliting" of data units.

Each data unit centroid was assigned an X-Y coordinate and the corresponding student population. The five schools were given X-Y coordinates and total enrollment constraints, so that the allocations would be within the building capacity of each school. Goodchild's model allows the insertion of barriers to movement in the

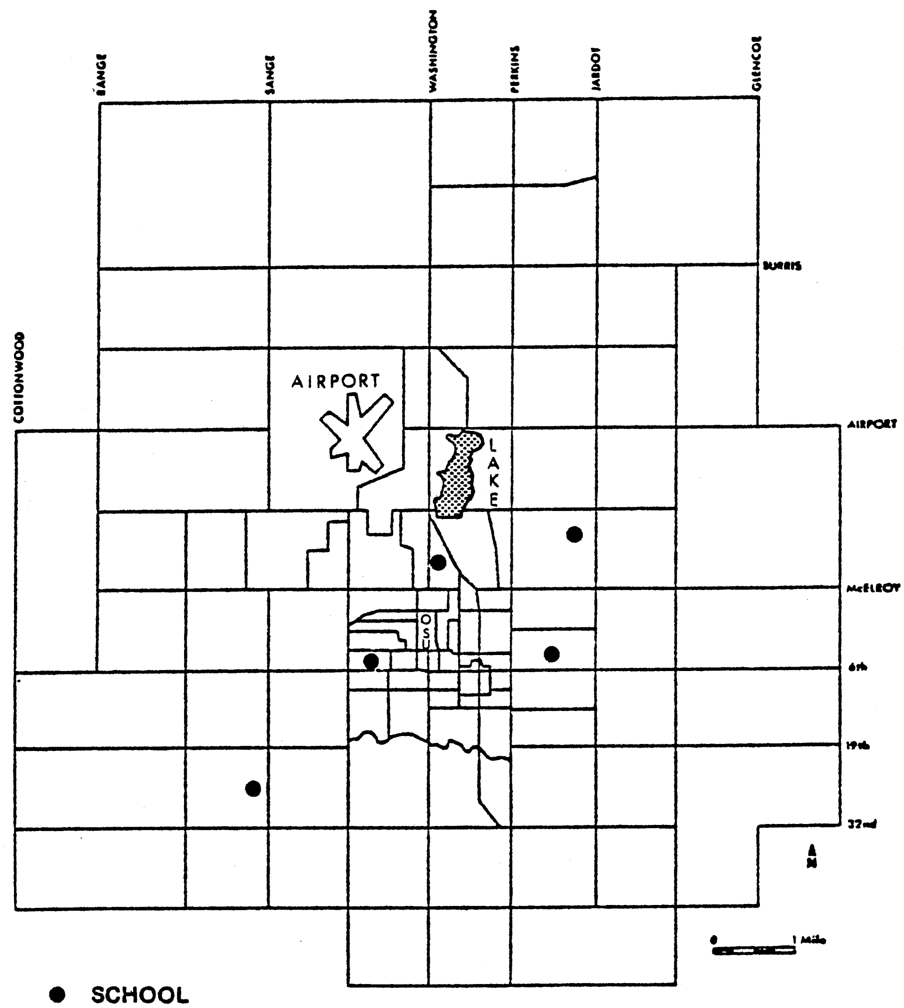

Figure 2. The Stillwater Study Area and Data Units

form of lines between two X-Y points. Three geometrical barriers were used to represent actual transportation barriers posed by Boomer Lake, Stillwater Airport, and the Oklahoma State University Campus. In addition, a grid option was used which forced the model to calculate right angle distances, so that the actual rectilinear "transportation grid" might be better replicated.

The Model Solution

The allocations of each TDZ's population to the appropriate school, in a distance minimizing manner, can be seen in Figure 3. It should be noted that although the allocations are represented as straight lines, the algorithm actually calculated a solution using right angle distances. This solution generated a minimum transportation cost figure of 2177 one-way passenger miles. Again, one must note that since a bus can carry approximately 50 children, the actual total mileage is much lower.

The solution shown in Figure 3 provides a fine example of the utility of the model. School districts were delineated which possessed reasonable compactness while maintaining the limits set by the building capacities. This solution would require little "hand manipulation" to polish out allocations that could not be implemented. An example of allocations that probably would not be

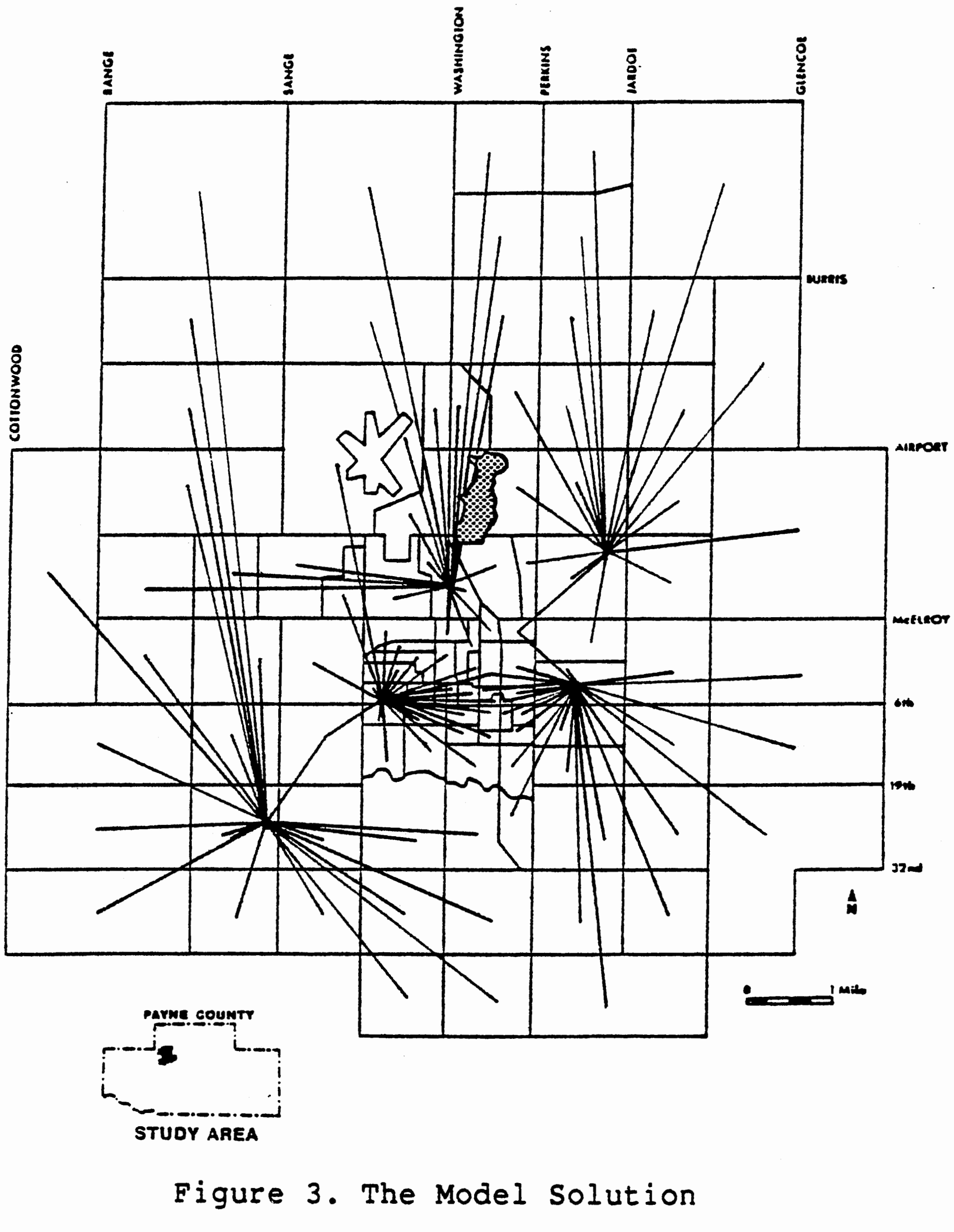

Figure 3. The Model Solution

operationally acceptable are those which cross other allocation selections, such as the allocations from the three data units north of McElroy and west of Sangre road, and the airport data unit. These allocations were probably made so the school capacity constraints of the Sangre Ridge and Westwood Schools (the two southwestern schools) could be met.

An example of a allocationally "split" data unit can be seen in the data cell directly northeast of the intersection of 19th street and Sangre road. The program provides an allocation matrix that indicates the number of children involved in each allocation from a split unit, yet the analyst must spatially divide the data cell into areas which contain the number of children indicated by the program. In addition, the political and operational attributes must be considered when dealing with a split data unit. Patron dissent might be aroused if children on one side of a neighborhood street attend a different school than the children on the other. This supports the previous comment concerning the selection of "natural" data units. By selecting appropriate data cell boundaries, a large percentage of such problems can be avoided.

The Impact of Scale

The quality of the computer solution shown in Figure 3, is undoubtably influenced by the five scale components that were outlined earlier. Each component's particular impact in the Stillwater example is discussed below.

Physical Aspects. The small physical size of Stillwater reduces the complexities of the problem. Distance is not a difficult factor due to the small size of the study area. All points in the city can be reached within a few minutes. This would also simplify research in the delivery of emergency services, since time is a crucial parameter in this work, (McClendon, Oehrtman, and Doeksen, 1978).

The small target population reduced the "sheer numbers" of the analysis, and increased the ease in gathering reliable population data. In general, the larger the data base the greater the chances for error.

The study area land use patterns and barriers did not introduce any major difficulties. The three existing transportation barriers, Boomer Lake, the Stillwater airport, and the O.S.U. campus, were accounted for in the determination of the solution.

Sub-units. No significant "sub-units" were evident in this study. Certainly, areas with homogeneous demographics such as the O. S. U. Married Student Housing, and the Sangre Ridge development can be identified, yet, this is not necessary for this research.

The school system hierarchy is organized so _all_ students attend the same middle school, junior, and senior high school, therefore achieving the social integration of _all_ demographic classes. No facility exist that serves a demographically "pure" population. This also removes the constraint of redistricting the elementary boundaries so that the proper "feeder" population for the middle, junior, and senior high school capacities is obtained.

Population Behavior. The small size of the target population in Stillwater simplifies the analysis of population behavior and aids in the examination of social interaction processes. It is much easier to assess the population growth and mobility in Stillwater, Oklahoma, than Houston, Texas. As previously mentioned, this research only utilized the current population. If population projections had been used, examination of the population growth and mobility in the study area would have been necessary.

Ecological Organization. The ecological organization of Stillwater's population poses no serious considerations that greatly affect the problem or solution. Since the population is small, and a large portion of the child producing population is associated with the University, little social stratification exists. Although there are different socio-economic levels, generally, none of the levels are segregrated in the delivery or consumption of public goods. The organization of the Stillwater schools provides and example of this point. All students attend the same middle, junior, and senior high schools.

Jurisdictional Organization. The jurisdictional organization of Stillwater reduces the complexities involved in execution of this analysis. The operational mechanisms of the Stillwater public goods sector are contained within one political entity, namely, the City of Stillwater. When developing the pioneering version of a public facilities location paradigm, Tietz (1975) used a single unit jurisdictional structure as the political framework for his theory. He implies that a uni-jurisdictional structure (such as Stillwater) is the most basic of political formats, and therefore, is the easiest to work with.

In a uni-jurisdictional environment, the hierarchy is clearly defined along with the operational methods and objectives. The information systems within this type of environment are usually effective and efficient. This makes the gathering of information much easier, and probably increases the chances of accurately examining and evaluating the information. A study is complicated when the analyst must obtain data from three or four different political units. In addition, the seperate political bodies may utilize totally different measures for evaluating growth, which could make comparison or assimilation of the information infeasible. The political implications of operating within two or more administrative units are tremendous. Some form of conflict is more likely to arise in the multi-jurisdicational environment.

The Stillwater study illustrates that the analyst must perform various editing functions when interpreting the computer solution. This example would have been more complex if population predictions had been included, since the population behavior component would have instituted a greater bearing on the solution. The solution displayed in Figure 3 could be implemented with very slight modifications. For the Stillwater (small scale) problem, location-allocation models are quite useful as analytical or evaluative tools and planning aids.

Example II: Putnam City Elementary Schools

Background

The Putnam City School System is an independant educational organization that is located in the west-northwest section of Oklahoma City, Oklahoma. The district provides an education for approximately 9,000 students, and contains a total population of approximately 97,000, in comparision to Stillwater's 4,000 students and population of 42,000. The areal size of the Putnam City district is close to 25,000 acres, which is approximately 1.6 times the size of the Stillwater district. The school system is comprised of 15 elementary schools (grades K-6), four junior high schools (grades 7-9), and three senior high schools (grades 10-12). The capacitites of the 15 elementary schools range from 425 to 775 students. The district is contained within three jurisdictional entities, The City of Bethany, The City of Warr Acres, and The City of Oklahoma City. One enclave, the Bethany School System, is completely surrounded by the P. C. (Putnam City) district, but even it's boundaries do not coincide with the Bethany city limits.

Goals of the Analysis

As with the Stillwater example, the goals of this study are to optimally delimit elementary attendance zones, and to examine the impact of scale upon the problem content and model efficiency. Since the Stillwater example suggested that complexities would increase with a increase in problem scale, a different analytical approach will be used.

A computer solution will be generated at the aggregate level to analyze the Putnam City system as a whole. In addition, the elementary school system will be broken down into "sub-units", and the redistricting of two select areas will be performed. The two approaches will then be compared to evaluate the differences in model efficiency and scale impact.

As in the Stillwater study, the analysis will be executed with the assistance of Goodchild's Location-Allocation Package, (Goodchild, 1973).

Data and Data Units

The 1980 U. S. Census provided the data base which consisted of all children between the ages of 5-11 that resided in the P. C. district at the time of the census (U. S. Bureau of Census, 1980). This data was originally collected for use in the study Putnam City School District: Analysis of Population Trends and Elementary Attendance Zones, by Tweedie and Pooler (1983). The 5-11 age group corresponded to the K-6 grade level in 1980 and therefore were identified as the "target population" of the study.

The 103 data cells were organized as shown in Figure 4. The selection of data cells that are not homogeneous in size and shape is consistent with Morrill's (1973) statement concerning the selection of "natural" data units in lieu of "geometric collections of people." Familiarity with the study area allowed the spatial delimitation of "perceptual neighborhoods" so that the data units reflected the cohesive and unified attitudes of the

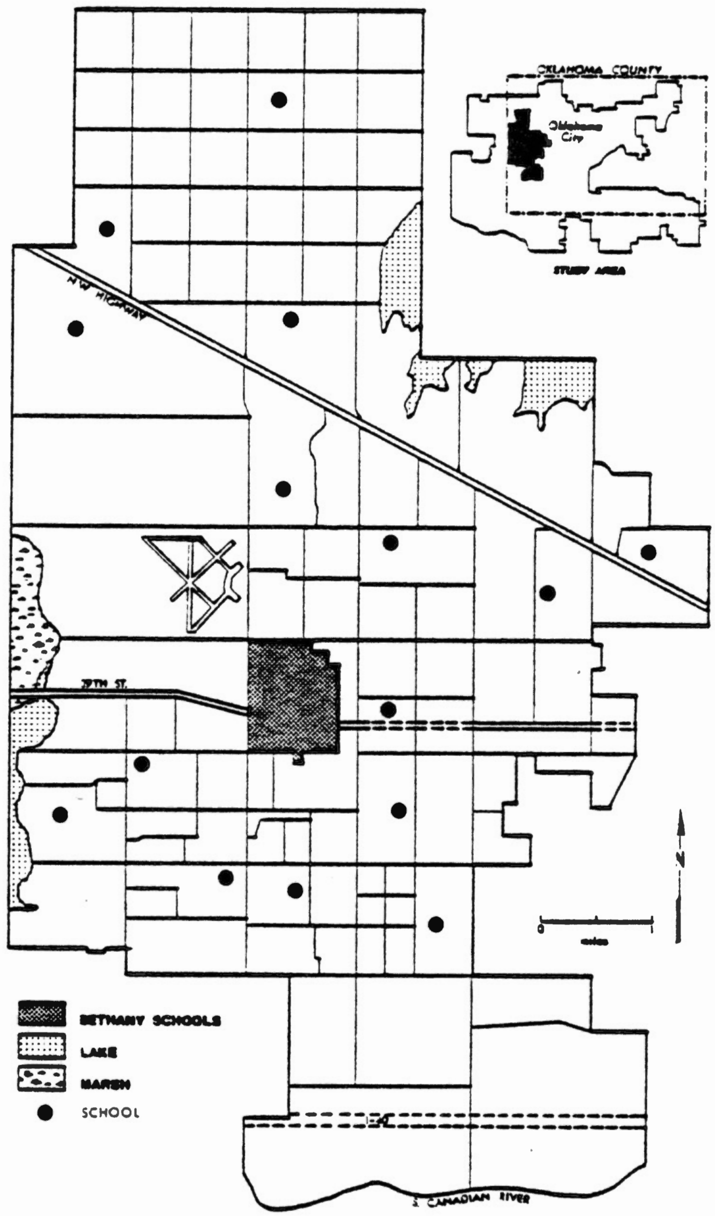

Figure 4. Putnam City Data Units and School Locations

population. Morrill (1976) contends that a model's success depends upon the knowledgeable selection and organization of input data in a manner that enhances the probability of generating a solution that can be operationally implemented.

The Southern Region. The data units in the southern one-third of the district (the area south of 39th street) exhibit large variation in areal size. These units were selected with the intent of creating "natural" data units and maintaining "perceptual neighborhoods". In the areas particularily close to the schools, large data units were delimited under the premise that these areas unquestionably would and should be assigned to the nearest school by the model. This assumption aids in organizing the data structure in the best economical and operational order.

Areas that were along the anticipated boundaries of the projected school districts, were considered "tradeoff" areas, and were assigned smaller data cells in hopes of "fine tuning" the allocational selections. By attempting to "forecast" the model solution a better computer solution can be achieved and the problem of "split" data units can be reduced.

The small areal size of the southern data units resulted from the very high population density and the absence of undeveloped acreage. In addition, the existing school districts, which were quite sprawling in some areas, contributed to the selection of the data units. The Census geography also influenced the determination of these data units. When using census data it is very inconvienient to split census blocks. In most cases the data units were composed of selected groups of blocks. In the Southern region, no cell boundaries deviated from boundaries previously devised by the Census.

The Central Region. The data units in the central region (north of 39th and south of the N. W. Highway) ranged in size from moderate to very large, due to the composition of the area. The unit boundaries were influenced by the "natural" data unit concept, the existing school districts, and the lower density of the "target population" in this area. The maintenence of "perceptual neighborhoods" was a major priority.

In the western area of the central region some very large data units exist. The two units south of the N. W. Highway and north of the airport are the extreme examples. These very large units were created due to the characteristics of that particular area. In the large zone just south of the N. W. Highway, a very densely populated housing development exists. This development, named Northridge, is served by the Northridge elementary school, located in the development, (Figure 5). To the south and east of the development, no growth has occurred,

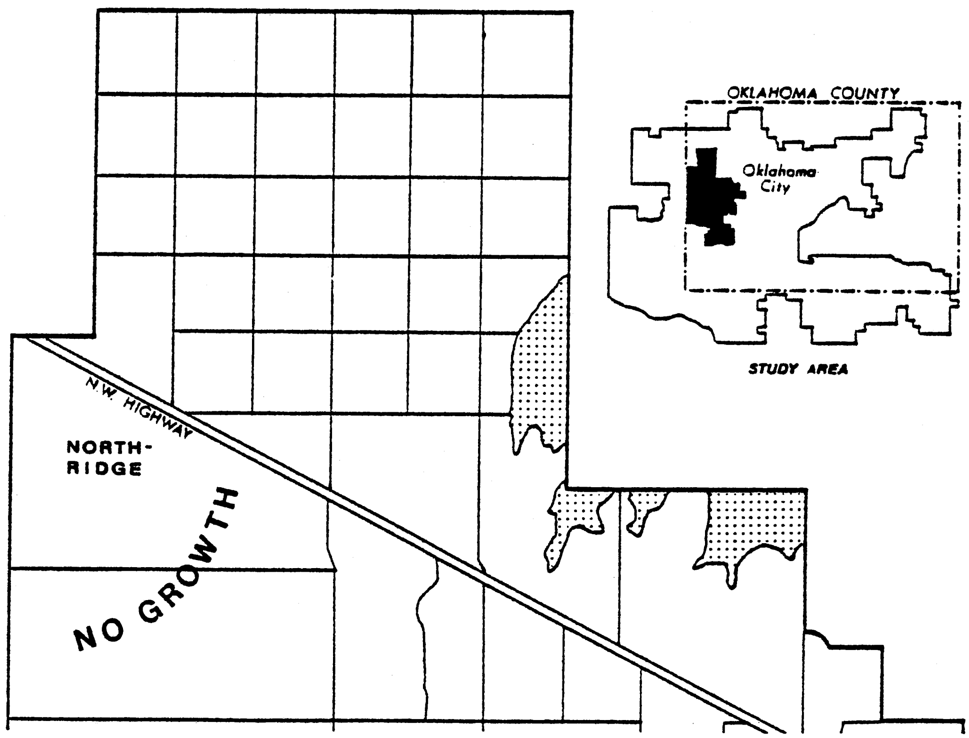

Figure 5. The Northridge Area

partially due to the zoning restrictions brought about by the airport. This "isolated" environment and the absence of growth brought about the aggregation of the area into one cell. It is clear that the children in this area would attend the Northridge school. Since no housing development or children exist in the south and southeastern portion of this area, the design of a finer data cell grid is unnecessary. This provides an example of the impact of land use patterns on location-allocation problems.

The other two unusually large units, just south of the Northridge area, also have a very sparse population, and little development, therefore justifying large cells. In all three large cells the census data was organized by extremely large blocks. This also influenced the decision to create large data units, since division of census blocks is a difficult task.

The Tulakes data unit shown in Figure 6 also displays large areal size. The population density in this unit is very high, and mostly consists of apartment dwellers. Tulakes elementary school is located in this area, and is filled with children that reside in this unit. The close proximity of the school and the homogeneous characteristics qualify this area as a "perceptual neighborhood," therefore making the further division of this area undesireable.

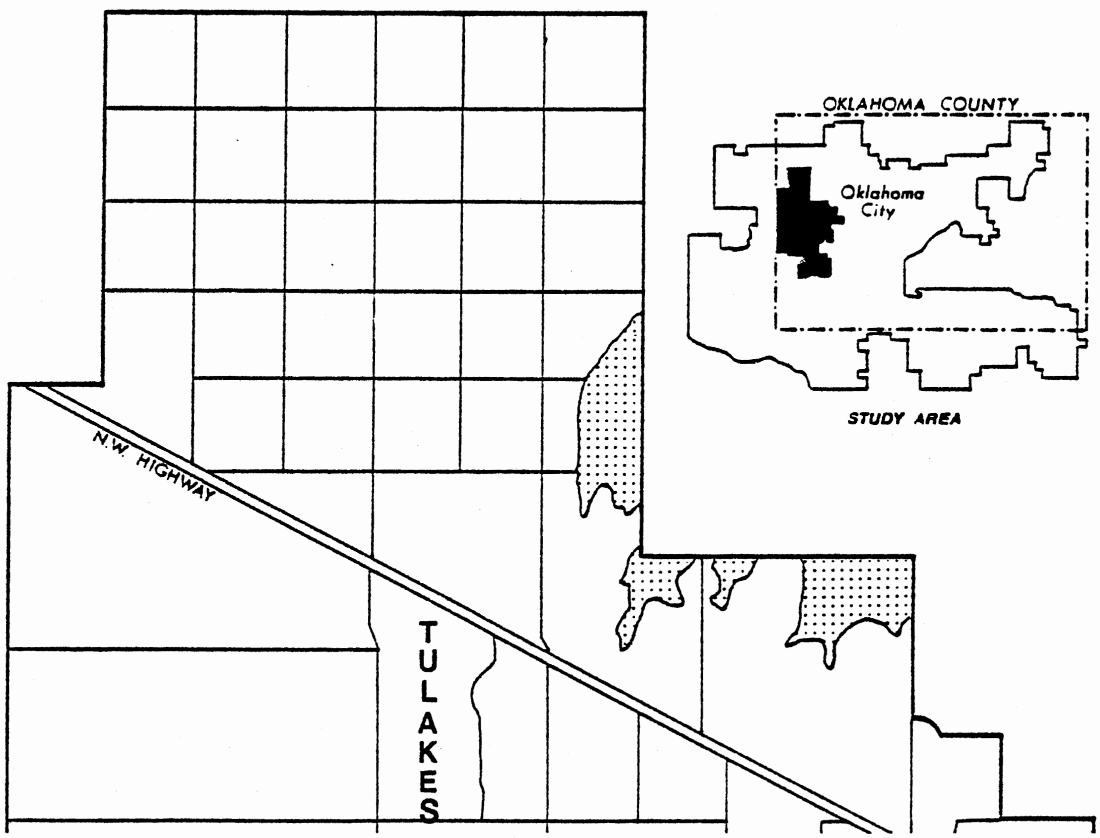

Figure 6. The Tulakes Area

The Northern Region. A well defined data cell grid pattern, based on quarter-sections, was used in the northern region. This was done for many reasons. The land use patterns greatly influenced the delimiting of the data cells. Development "gaps" existed with large tracts of land untouched. In the developed areas the street patterns were extremely winding within quarter-sections and displayed low linkage between quarter-sections. If streets had been used as data cell boundaries, and these boundaries identified as attendance zone breaks, then some very awkward zones would be established.

Another highly influential component was shape and size of the census areas. The census block, technically, is designed to contain an approximate population of 100. This was not so in the northern region. Blocks existed which contained 400-500 individuals. Clearly, the census units had not been updated to account for the development. As shown in Figure 7, block 101 wraps around portions of several developments and includes an entire section (except for blocks 102 and 103 in the southeast corner), so that the residents of this block are actually seperated by considerable distance. This hindered the use of pre-defined census boundaries in delimiting the data cell boundaries.

The boundaries of the existing northern school zones were set along major traffic routes, which followed the

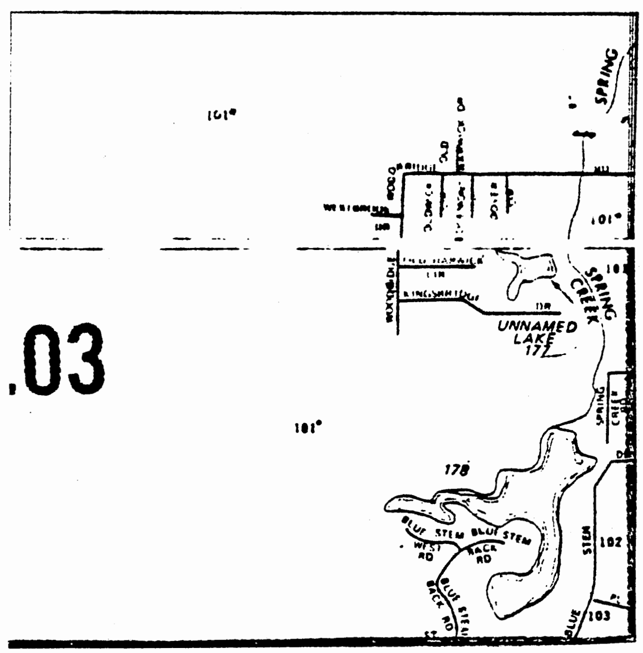

Figure 7. Census Block Example

township and range grid pattern. This also influenced the decision to develop a grid type data base. In addition, the majority of neighborhoods were contained within a quarter-section. Using data cell grid units corresponding to quarter-sections allowed the allocation of complete neighborhoods, thereby reducing the potential political ramifications.

It should be noted that the northern data cells were also used in the demographic study of Putnam City, conducted by Tweedie and Pooler (1983). In that study, housing growth and population projections were developed. The housing growth data, provided by Oklahoma City, was organized by quarter-sections, thereby influencing the decision to aggregate by the same unit.

In summary, many factors were considered in the determination of data units. The scale of the problem clearly brought attributes into play that were not encountered in the Stillwater example, such as outdated Census data units, large "gaps" in development, isolated developments, and the hierarchical nature of the Putnam City System.

The Aggregated Model Solution

The aggregated model solution is shown in Figure 8. As in the Stillwater example the map presents the allocations as straight lines, while the algorithm

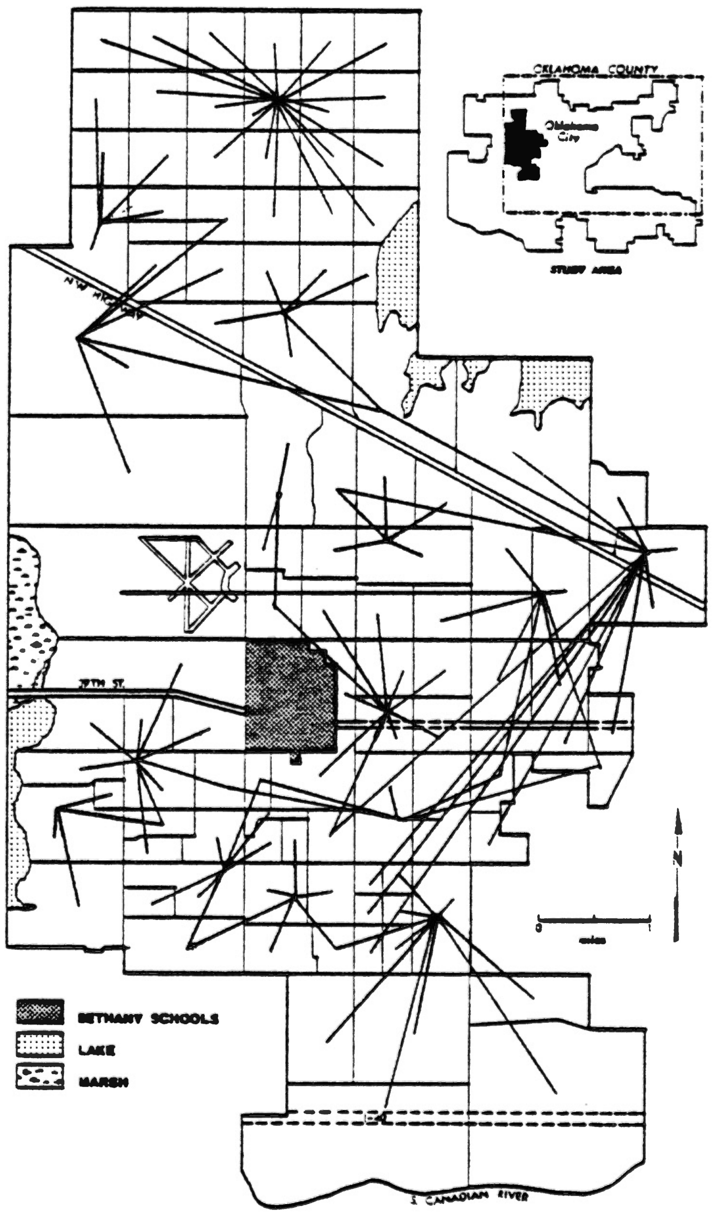

Figure 8. The Aggregate Solution

calculated right angle distances. The solution generated a total cost of 6154 one-way passenger miles. In reality, the actual total mileage is lower, since a bus can carry up to 50 children.

The solution shown in Figure 8 reveals several problems inherent in a completely computerized solution. The solution contains many allocations that crossed other allocation lines. A large number of data cells with "split" allocations were created. Allocations that moved children past one school to a more distant school are present in large numbers. In addition, this solution for elementary attendance zones would require wholesale changes in junior and senior high attendance boundaries as well.

This solution is confusing and contains allocations which are almost unthinkable. Although this solution provides the optimal transportation solution, it is politically and operationally infeasible. From a planning and administrative perspective this solution is nearly worthless. In Hall's (1973) locational-allocational analysis of Chicago Public Schools, the computer model solutions were also confusing and operationally impractical.

The contrast between the two examples shows how the scale of a problem influences the model's ability to generate an applicable solution. At the Stillwater (small) scale, the model calculated a very reasonable and workable solution; the aggregated Putnam City solution was a literal "mess". How can the impact of scale be handled so that a helpful solution can be derived?

By seperating the district into it's natural "sub-areas", an analysis at each sub-level might provide solutions that can be reassembled into a single working solution. This would not only be optimal for the total system, but include solutions that are more "personalized" for each sub-area.

Fortunately, The geography of the Putnam City system suggests three distinct "sub-areas" defined by the existing school system hierarchy. As shown in Figure 9, three high school and four junior-high catchment areas exist in the Putnam City system. Area 1 contains 1 high school, 1 junior high school, and 4 elementaries. Area 2 contains 1 high school, 1 junior high school, and 5 elementaries. Areas 3A and 3B contain 1 high school, 2 junior high schools (one in 3A and one in 3B), and 6 elementaries.

Since the junior high schools and senior high schools are "fed" by the elementary schools, adjustment of the elementary zones across either the junior or senior high school boundaries would disturb the current balance. In Tweedie and Pooler's Putnam City study (1983), the administration requested avoidance of elementary boundary

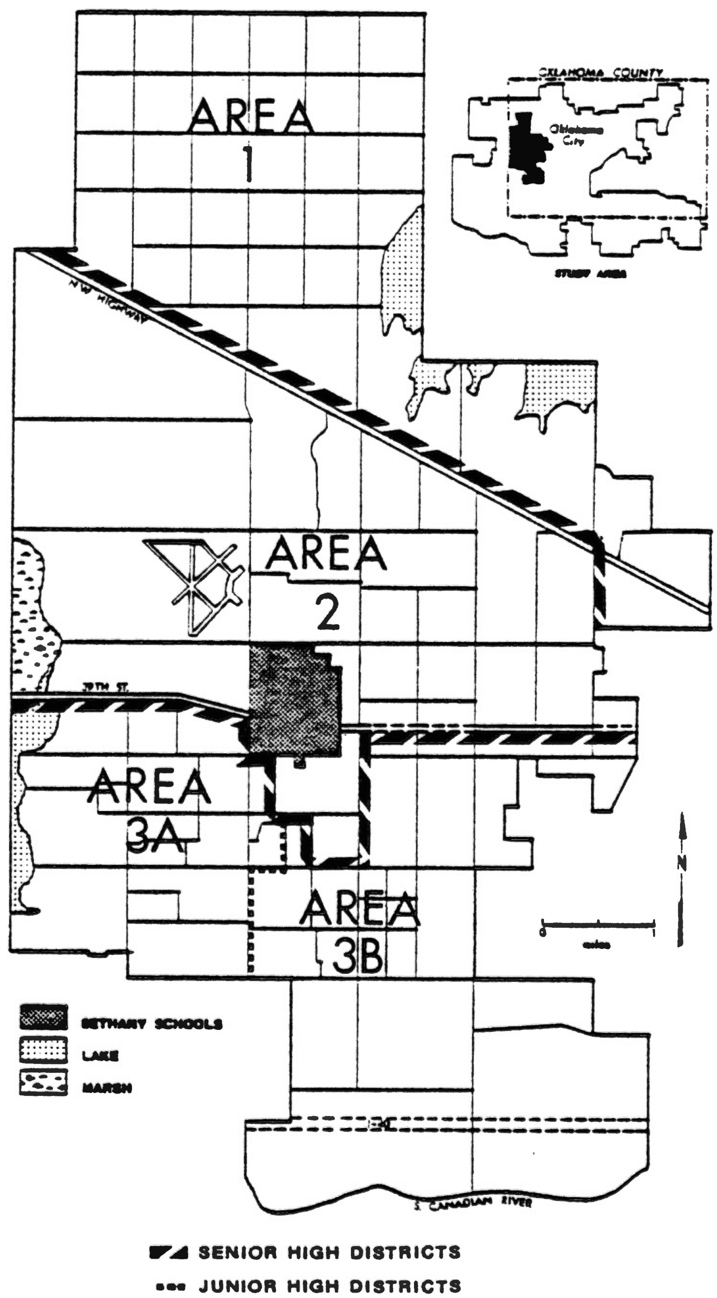

Figure 9. Junior and Senior High School Catchment Areas

changes that would affect the enrollments and catchment areas of the junior and senior high schools. In essence, this requires that the redistricting of elementary boundaries occur in three seperate units.

The Disaggregate Solutions

In the following examples, two of the three "sub-areas" were analyzed individually to demonstrate that dis-aggregation of the total problem develops finer solutions, and improves model effectiveness, thereby supporting the hypothesis that scale directly influences methodologies and solutions.

The Southern Solution. Figure 10 displays the solution for the southern region. Comparison of Figure 8 and Figure 10 shows that the disaggregate solution is a great improvement over the aggregate solution. No overlapping allocations result and only five data cells are split. This solution also maintains the southern senior high school boundary, and only institutes one minor change in the junior high school catchment areas.

The Northern Solution. By comparing Figure 8 and Figure 11, the increased utility of the disaggregate solution can be seen. No overlapping allocations are generated by the disaggregate run, and only one split data cell occurs. The disaggregate solution is clearly a finer

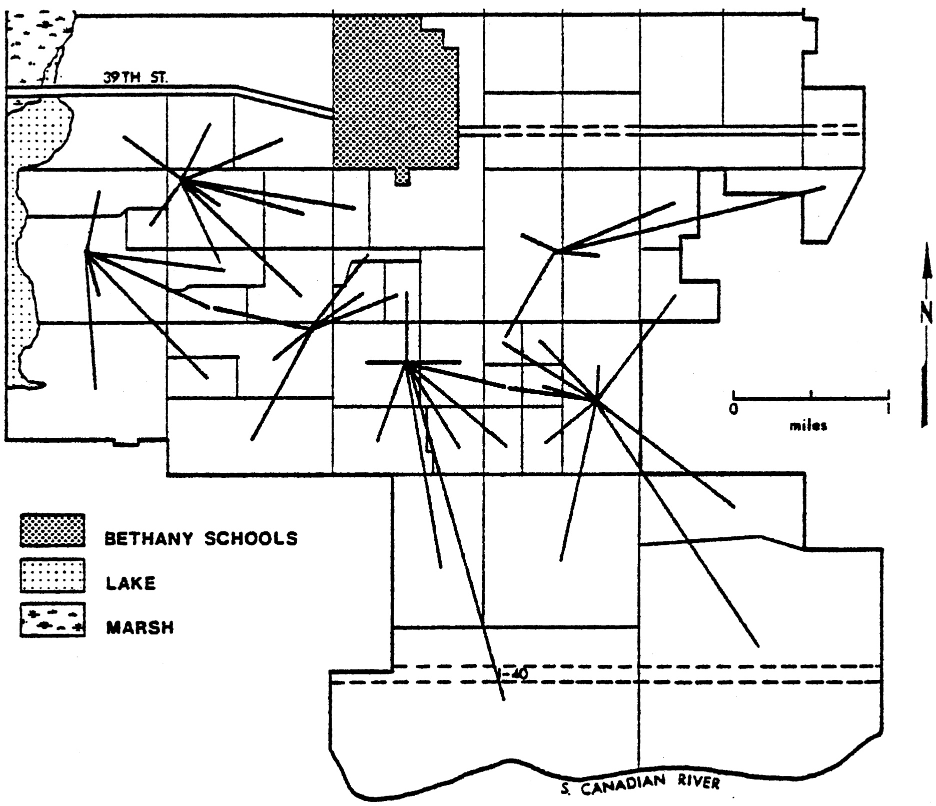

Figure 10. The Southern Solution

solution than that generated in the aggregate run, and could be implemented with minor resistance.

In summary, the comparisions of the aggregate and disaggregate solutions support the premise that scale directly influences model effectiveness and the methodologies that should be utilized in execution of an analysis such as this.

The Impact of Scale

Many of the problems that surfaced in this analysis, and in the Putnam City demographic study (Tweedie and Pooler, 1983), revolved around the scale of the problem. The five scale variables, and their particular attributes in the Putnam City problem, are discussed below.

Physical Aspects. The physical size of the Putnam City school district introduced many complexities into the problem. The large "target" and general population complicated the ease of gathering reliable data. Size literally forced the use of U. S. Census data, which introduced a number of problems not encountered in the Stillwater study. The land use patterns in the Putnam City district also confused the issue. As mentioned previously, development of the data cells was complicated by street patterns, varying population densities, and "patchy" growth patterns.

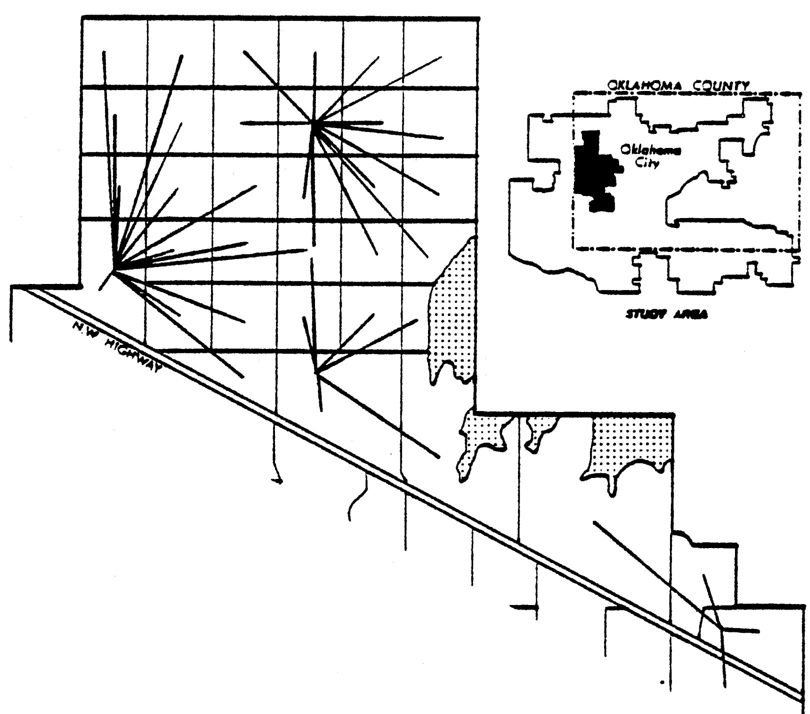

Figure 11. The Northern Solution

Sub-units. The Putnam City school system hierarchy posed no extreme difficulties, but did constrain the methodologies and solutions. Actually, the hierarchical organization suggested the need for a disaggregate analysis. The existing school districts also affected the study by influencing the boundaries of the data units. The "natural" sub-units of this study, namely the "perceptual neighborhoods", additionally influenced the determination of the data cells. Efforts were made to avoid the division of areas that were identified as "neighborhoods".

Population Behavior. The large population in the Putnam City district not only increased the chances for enumeration error, but also complicated the examination of population behavior. In this thesis, a stable population was utilized, so projections of the future population and urban growth patterns were not included. In the Putnam City Demographic and Elementary Attendance Zone Study, population and housing growth projections were developed, (Tweedie and Pooler, 1983). This required the assessment of mobility, both into and out of, as well as within the study area. Because the study utilized 1980 census data, the task of updating the information to 1982 was essential. This itself is no simple task.

The monitoring of housing and urban growth patterns also proved quite difficult. Since the data involved three seperate municipalities, collecting and summarizing the housing growth data proved trying. It often seemed that a new housing project was initiated, and the ground broken, before the legal documentation could be completed, and the municipal records updated. It is quite frustrating when, near the determination of a solution, a new housing project is approved that completely invalidates the proposed plan.

Ecological Organization. The ecological organization of the population in the Putnam City district was very complex and diverse. A large population often contains extreme socio-economic differences, and this study population proved no different. Large demographic variations existed in the population base. For example, families as a percent of occupied households ranged as high as 91% and as low as 50%. In the Tulakes area (shown in Figure 6), 69% of the population lived in rental units. In contrast, the Northridge area (Figure 5) contained only 7% rentors. Futhermore, the demographic status of the rental population was quite varied. In some areas, families comprised as much as 70% of the rental population, while in others only 24% of the renters were families. In addition, some areas possessed populations with a large number of children per family, while other areas had few children per family. High growth areas, such as the northern section, contained families with very young children, while other areas contained families that had only older children, (Tweedie and Pooler, 1983). In 1980, the median value of households in the Ski Island area (northern region) was approximately $ 110,000, while in some other areas the median value was approximately $ 50,000.

Another factor that proved significant was the varying age structure of the "target population" in each data cell. For example, the Northridge area (Figure 5) student population was comprised of very young children, grades 1-3. Since the capacity constraints of each school reflects the capacity of all grade levels, this factor could pose a problem. The computer allocation of the total Northridge population may provide more children of grades 1-3 than the school can handle, and may not supply sufficient children to fill the 4-6 grade classrooms.

Unlike Stillwater, many sections of the social strata in the Putnam City area <u>are</u> segregated from others. In the delivery of educational services, facilities <u>do</u> exist that serve demographically "pure" or homogeneous neighborhoods. Although all of the facilities and services provided by Putnam City are of high quality, this may propagate feelings of unfair treatment.

Many different political opinions arise from the large variations in the socio-economic characteristics of the population. Homeowners tend to view rental families as "transients" whose desires and welfare come second to their own. Naturally, when any undesirable changes are proposed, homeowners suggest to "do it to the apartment complexes".

At this time, the Putnam City district does not experience any racial tensions. If racial integration and balance constraints are added to the redistricting problem, enormous political and operational complications result. Hall (1973) addresses this problem in his study of the Chicago Public School System.

In contrast to the Stillwater example, the Putnam City district contains very defined demographically pure segments. In some ways, this aids in delimiting the "natural" sub-units, but complicates the political scenario so that an equitable and politically suitable solution is harder to derive.

Jurisdictional Organization. The greatest jurisdictional problem in this analysis was the gathering and organization of the data. The census boundaries do not coincide with the three jurisdictional boundaries; census tracts often overlapped two jurisdictional units. Since the census data is grouped by jurisdictional entity, data in a single census tract frequently had to be taken from two seperate census listings.

Another problem was the acquistion of urban growth data from three seperate municipalities. In some instances, the data was not organized in similiar format.

The time factor of gathering the data also proved significant.

The fact that the Putnam City district is contained within three seperate political jurisdictions did not introduce major problems into the analysis. Because Putnam City School System is a legally independent system, they do not experience the majority of political problems that most tri-jurisdictional entities encounter. The Putnam City system must work with all three municipal agencies, yet they are not directly accountable to any single jurisdiction.

The organizational structure of the Putnam City system is well defined and operationally efficient. This provides good communication within the system and to the school patrons. Public input is welcomed and fairly evaluated. The system possesses a fine communications and information network, which allows the analyst to gather school data with relative ease. This analysis would have been much more difficult had the Putnam City information system been inefficient.

Results of the Analysis

This analysis supports the hypothesis that problem scale directly influences the efficiency and effectiveness of location-allocation models in public facilities locational problems. The small scale problem can be adequately solved without special treatment. The impact of the five scale variables on the Stillwater analysis was relatively minor, and no extreme complications were encountered. A quality solution that required little hand manipulations was generated. The school districts that were identified could be implemented with little resistance.

By contrast, in the Putnam City example the aggregate solution is both politically and operationally infeasible. This indicates that the scale components at the intermediate level reduce the computer solution efficiency. The disaggregate solutions also indicate the impact of scale. By analyzing the Putnam City problem in the disaggregate manner, analogous to several small scale problems, excellent solutions were calculated that satisfy the political and the operational requirements. The impact of the scale variables was much greater at the intermediate problem scale, creating more difficulties in the derivation of an adequate solution.

Example III: The Internal Revenue Service Regional Districts

This section uses the regional districts of the Internal Revenue Service as a "real world" example of a large scale problem. It does <u>not</u> include a location-allocation analysis, as was done with the Stillwater and

Putnam City cases, but provides an examination of the impact of the scale components at the large scale level.

Background

Figure 12 displays the locations of the regional headquarters and the corresponding service districts of the Internal Revenue Service. The functions of these offices include administrating the service district, providing personnel services, and conducting audits within the district. All offices are under the jurisdiction of the Internal Revenue Service and the United States Government.

The "target population", or consumers of the good, can be defined as all individuals or business that file tax returns with the United States Government.

Physical Aspects

The physical size of the area (the fifty states) naturally influences the problem content. The large "target population" would not create any significant difficulties in data gathering since the information could be obtained with ease from the records of the Internal Revenue Service. The impact of the physical geography of the study area at this scale is limited to major barriers to transportation (such as the Rocky Mountains), and maximum acceptable distance. From a geographic point-of-

Source: The U.S. Directory of Federal Regional Structure 1981-82

Figure 12. The Internal Revenue Service Districts

view, with only seven centers, the level of service provided to states like Wyoming and Montana, or Alaska and Hawaii, will be marginal at best. The land usage component is irrelevant at this scale.

Sub-units

Since individuals or businesses are identified or classified for taxpaying purposes according to the state of residence, the "natural" sub-units would consist of the states themselves. The boundaries of the current districts do not divide any states. If the allocations were not to cross current state boundaries, then "sub-units" consisting of anything smaller than a state would be unnecessary.

Population Behavior

At this scale, only regional population movements resulting in a net change, are relevant. For example: population movements to the Sunbelt, and business headquarters movements to the Sunbelt. These would increase the "processing" load at the southern centers such as Atlanta and Dallas, and reduce the load in the northeast and northcentral centers. But this change would only require the leasing of additional office space instead of the construction of a new specialized facility (such as a school). This decision would be much less "emotional" than the construction of a new school.

Ecological Organization

The ecological organization component does not complicate the content of the subject. Since the service provided by the Internal Revenue Service is generally viewed as a necessary evil, that afflicts rich and poor, large and small, the feeling of prejudicial treatment is non-existant. The general demographics of the population (ethnicity, education, income levels, etc.) impose no constraints on solutions.

Jurisdictional Organization

Because the Internal Revenue Service is an agency of the United States Government, little jurisdictional conflict is likely. The Internal Revenue Service is the ultimate tax collecting entity, therefore they provide "final" decisions. Since all public facilities in a large scale problem would be administrated by the federal government, then a clear jurisdictional hierarchy exists. From the analyst's perspective, few jurisdictional complications would result.

In light of these scale components, the locations of the service centers, and district boundaries appear reasonable, although perhaps not ideal. Chicago and New York City appear to be off-center with respect to their service areas, although the large demand in those two cities help justify the locations. The assignment of Wyoming to the Dallas center might also be questioned, but to assess the spatial efficiency of the I.R.S. solution would require a complete analysis.

In summary, the Internal Revenue Service district example indicates that the five scale components are less complex at the large scale than at the intermediate scale. The results of the Stillwater and Putnam City analysis along with the discussion of the I.R.S. example indicates that the impact of scale upon model efficiency is as shown in Figure 13.

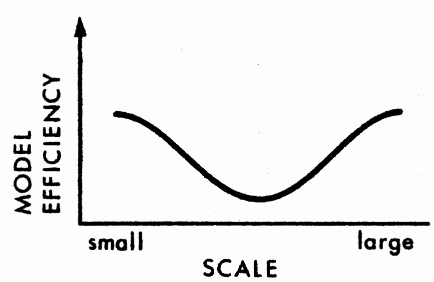

Figure 13. The Influence of Scale Upon Model Efficiency

CHAPTER V

CONCLUSIONS

> Modern urban man is born in a publicly financed hospital, receives his education in a publicly supported school and university, spends a good part of his life travelling on publicly built transportation facilities, communicates through the post office or the quasi-public telephone system, drinks his public water, disposes of his garbage through the public removal system, reads his public library books, picnics in his public parks, is protected by his public police, fire, and health systems; eventually he dies, again in a hospital, and may even be buried in a public cemetary (Tietz, 1975, pp. 277).

This statement summarizes the increasingly important role of public facilities in the development and growth of modern urban systems. Tietz's quote further justifies the examination of public facilities location theory and the impact of scale upon public facilities locational analysis.

Conclusions

Chapter IV indicates that problem scale directly influences the analytical environment and the model effectiveness in public facilities location-allocation analysis. Although this analysis only utilized one location-allocation model, the conclusions regarding the impact of scale should apply to similiar analyses utilizing different location-allocation models. Goodchild's LAP model, used in the analysis possesses, characteristics that are basic to the majority of location-allocation models. If this relatively simplistic model was affected and the solution complicated by study area scale, then it would seem appropriate to conclude that highly complex models (built upon the same basic concepts used in LAP) would also be influenced.

The reader should recall that study area scale not only affects the model, but also the general content of the problem. Modelling involves the transformation of qualitative situations into quantitative data, and interpreting the quantitative output into qualitative solutions. The integrity of any model solution is dependent upon the ability of the data to represent the actual situation. Since the "real world" environment entered into any location-allocation analysis will reflect the environmental scale, then any location-allocation analysis will be influenced by the scale variables.

The modelling of reality is an enormous task that contains many pitfalls. Generally, the Stillwater and the disaggregate Putnam City solutions are excellent technical solutions that leave little room for improvement, yet these solutions and the general model do contain weaknesses. For example, the model derives a solution as if each student travelled individually, when actually buses transport as many as fifty children at one time. If the analyst, using LAP, was to locate a single school to serve both a dispersed single family home neighborhood and a population that lived in an apartment, the effect of the "individual travel" calculation on the solution would be enormous. Using the individual travel assumption the routine would locate the school as shown in Figure 14. This solution "pulls" the school away from the residential neighborhood and towards the apartment population, therefore providing a non-optimal solution. The optimal solution with the children transported by bus, as in reality, is much different. This is shown in Figure 15. The "bus transport" solution locates the school within the residential neighborhood because of the efficiency of bussing a group of students from one specific location such as an apartment complex. This "hand generated" solution is clearly a better solution than the one that would be generated by the computer.

In addition, the model cannot determine what is, or is not, a politically feasible solution. In the Putnam City Demographic Study, politics greatly influenced the decisions. The proposed allocational solutions were compromises of those that were logistically optimal and those that were politically acceptable. Smith (1971)

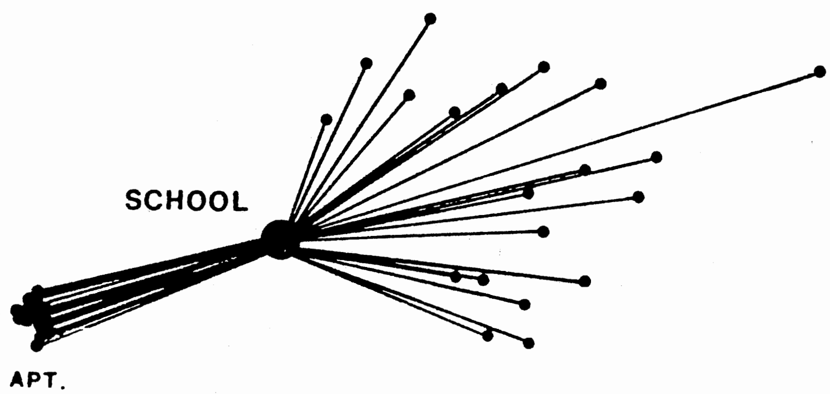

Figure 14. The Individual Travel Example

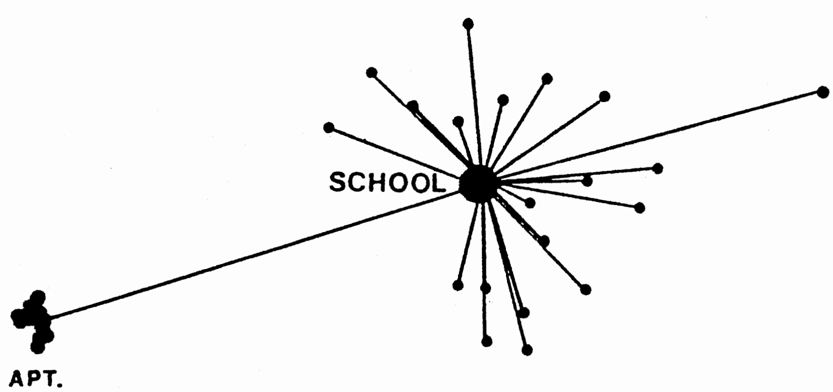

Figure 15. The Bus Transport Example

referring to this type of solution as "satisficing" rather than "optimizing", concludes that most locational decisions are of this type. Optimization requires "perfect" information and a decision-making ability that most individuals lack. Most decisions become a tradeoff between feasibility and optimization.

Clearly, location-allocation models are powerful analytical tools that provide the researcher with a base to work from. But, every model solution requires some form of manipulation by the analyst to develop a workable plan. Morrill (1976) contends that the success of a computer location-allocation analysis depends, in part, upon the users knowledge of the study area. This point is expanded in the comment:

> These methods of analysis are no panacea for pouring out 'optimal' solutions, since the real world with its immense complexity tends to defy exact analogs. The results of analyzing these models may be optimal and exact in reference to the models, but they are not necessarily the optimal results for the real world. RATHER, THE RESULTS ARE REGARDED AS AN AID TO THE ANALYST'S INTUITION AND NOT AS A REPLACEMENT FOR IT. Indeed, the greatest aid the models provide is a better understanding of the sensitivity of solutions to changes in parameters, constraints, or criteria. It remains for the analyst to select from among the 'good' solutions those which he feels meet the needs and demands of his region most closely (Revelle, Marks, and Liebman, 1970, pp. 692).

Prospects for Future Research

The prospects for future research in public facilities location and location-allocation modelling are unbounded. The impact of scale on location-allocation modelling is one area that deserves further research. Various models could be utilized in a similiar analysis so that model strengths and weaknesses, when subjected to varying scales, can be determined. In addition, computer analysis of the impact of scale upon a large problem, such as the Internal Revenue Service districts, warrants inspection.

The examination of the agglomerative tendencies of public facilities is another area that remains untouched. As mentioned earlier, facilities with definite service regions, such as schools, tend to be dispersed. Those facilities with undefined service regions, such as hospitals, tend to agglomerate. Certainly, some theories of public facilities agglomeration can be derived.

Another area that holds many prospects is the inspection of the Soviet, East European, and Chinese public facilities problem. In theory, all facilities in these nations are public. A large amount of work could be done comparing the political and operational environments of the public facilities planning strategies in these centrally planned economies. Smith (1971) mentions that the political environment of the economy is one neglected aspect of location studies. Clearly, the criteria for locational optimality would differ in these economies.

The application of computer models to solving location-allocation remains in its infancy. Their future may be limited less by theoretical and technical developments than by man's inability to translate the qualitative complexities of real world problems, as discussed in this thesis, into the quantitative type of format required by computer models.

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