DISPARITIES IN THE DISTRIBUTION OF MUNICIPAL SERVICES

by

ROBERT MARLAY
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Certified by . . . . . .
Thesis Supervisor

and . . . . .
for the Department of Urban Studies and Planning

Accepted by . . . .
Chairman, Departmental Committee on Graduate Students of the Department of Urban Studies and Planning

and. . . . . . .
Chairman, Departmental Committee on Graduate Students of the Department of Civil Engineering

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ABSTRACT

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Submitted to the Department of Civil Engineering and to the Department of Urban Studies and Planning on June 25, 1971 in partial fulfillment of the requirements for the degrees of Master of Science and Master in City Planning.

This research addresses the subject of disparities in the distribution of municipal services. Municipal services, in this study, include refuse collection, rat control, the installation and maintenance of storm and sanitary sewerage, curbs and gutters; street and sidewalk surfacing and repair, street cleaning, snow clearing, street lighting and traffic control; the provision of water, gas and electricity; police and fire protection; and the provision of open space, recreational facilities and other environmental amenities. Numerous cases of disparities are documented and the sampling suggests that the problem is widespread and that the magnitude of unequal treatment is often quite large. Ethical and legal arguments are offered in support of more equitable distributions. Legitimate standards by which equity might be determined are discussed and the practical difficulties of implementing these are exposed.

From several sources of information, including the author's research of Cambridge, Massachusetts, the nature of the "process" which determines how municipal services are distributed is conceptualized and explicitly modelled. Relying upon this conceptualization, the discussion then offers to explain why disparities exist and suggests that those most commonly denied adequate municipal services are best characterized as powerless and poor. Lastly, the strategies of political incorporation, citizen involvement, confrontation, litigation, legislation, subsidization, research and innovation are briefly mentioned, and some speculations are made upon the implications of their possible successes. As an aid in understanding the long range effects of different combinations of strategies, the distributive process was modelled on a computer and several strategies were simulated with insightful results, and these are referenced at several points in the discussion.

In the Appendices, a study relating participation rates in the consumption of public services to socio-economic factors is summarized, a listing of the computer model for the distributive process for refuse collection is provided, and the author's analytical work concerning the routing of public sector vehicles is presented as one illustration of the many possible applications of research and innovation to municipal service systems.

It is concluded that disparities in the distribution of municipal services seem destined to exist, not because there is a lack of strategies which can eradicate them, but because their existence appears to be an essential thread woven into the fabric of stable communities. Disparities appear to have a necessary and desirable function for all concerned. This is not to say, however, that anyone should be denied adequate municipal service, and towards this goal many strategies can be applied.

Thesis Supervisor: David H. Marks
Title: Assistant Professor, Department of Civil Engineering

Thesis Supervisor: Martin Rein
Title: Professor, Department of Urban Studies and Planning

Thesis Supervisor: Lisa R. Peattie
Title: Associate Professor, Department of Urban Studies and Planning

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I. INTRODUCTION

> In the new industrial towns, the most elementary traditions of municipal service were absent. Whole quarters were sometimes without water even from local wells. On occasion the poor would go from house to house begging for water. . . . Open drains represented, despite their foulness, comparative municipal affluence . . . . Block after block repeats the same formation: there are the same dreary streets, the same shadowed, rubbish-filled alleys, the same absence of open spaces . . . . [T]hose who speak glibly of urban improvements during this period . . . fight shy of actual facts: they generally impute to the town as a whole, benefits which only the more favored middle-class minority enjoyed. . . .[1]

In the above passage, Mumford describes the residential environment of the new industrial towns of nineteenth-century England, yet his depiction of the past is hauntingly similar to those of urban and rural slums today.

Ghettos have long been characterized by poor municipal services.[2] Today, the familiar expression of the "wrong side of the tracks" elicits imagery, like that above, of the conditions resulting from the lack or inadequacy of such services: dimly lit, unrepaired, and often unpaved streets, rat colonies, accumulations of garbage, trash strewn in vacant lots, stagnant water at clogged sewer catch basins, unswept streets and inadequate traffic control. In sharp contrast, the more affluent neighborhoods under the same municipal jurisdiction usually receive municipal services so conscientiously that the inhabitants are rarely reminded of their vital importance. Such disparities in the distribution of municipal services among residents can be perceived in nearly every city and town in the country.

Yet evidence clearly shows that the impoverished are in no way less concerned about receiving adequate municipal services than are other segments of the population. The Report of the National Advisory Commission on Civil Disorders specifically cites as unrelenting sources of irritation and frustration the environmental conditions resulting from the non-existence or inadequacy of rat extermination, street cleaning and refuse collection services.[3] The Report also notes: "According to one Sanitation Commissioner, . . . residents bordering on slums feel that sanitation and neighborhood cleanliness is a crucial issue, relating to the stability of their blocks and constituting an important psychological index of 'how far gone' their area is. It must be concluded that slum sanitation is a serious problem in the minds of the poor. . . ."[4] Furthermore, as evidenced by legal suits in various parts of the country on behalf of the poor,[5] services other than those strictly relating to sanitation are also perceived to be important by the lower classes. These include the provision of stormwater drainage facilities and sanitary sewers, street and sidewalk surfacing and repair, street lighting, water supply and traffic control.

This argument alone suffices to say that municipal services <u>should be</u> distributed more equitably, but there are other compelling arguments. The Report links inadequate municipal services to domestic crises. "Virtually every episode of urban violence . . . was foreshadowed by an accumulation of unresolved grievances by ghetto residents against local authorities. . . . So high was the resulting underlying tension that routine and random events, tolerated and ignored under most circumstances . . . became triggers of sudden violence. . . . Evidence . . . establishes that a substantial number of Negroes were distrubed and angry about local government's failures to solve their problems."[6] Of these problems, the insecurity of self and property and poor health and sanitation conditions were cited among the most important. "Inadequate sanitation services are viewed by many ghetto residents not merely as instances of poor public service but as manifestations of racial discrimination."[7] Furthermore, the levels of services provided by municipalities appear to be correlated to such health indicators as rat bites per thousand children, maternal and infant mortality rates and life expectancy. This link alone, however vague it may be, carries with it implications of awesome responsibility on the part of administrative officials. Inadequate police protection has often been cited as contributing to the higher crime rates (35 times higher in some instances[8]) in the lower income Negro districts.

Lastly, the levels of municipal services are important indicators of governmental efficacy. Poor services are interpreted by residents simply as municipal neglect--an interpretation which easily fans the fires of discontent, and which is amplified in areas where high population density creates more intense needs for services and where the lack of open space and the uses of streets as outdoor living rooms and recreational areas produce higher visibility and sensitivity to the conditions resulting from poor services.

Summarizing, municipal services are as important or more so to the disadvantaged as they are to the more affluent, inadequate services have been linked to social unrest and the levels of municipal services are often used as valid indicators of governmental efficacy despite how well the government might perform other more intangible services. Furthermore, there is an underlying feeling pervading all these arguments that municipal services should be distributed equitably and without regard to racial, social or economic factors. Yet vast disparities persist.

In the face of this persistence, two questions emerged to motivate this thesis: why do they persist, and what can be done about them? The goal is clear--to ameliorate the suffering, in some cases, and irritation, in others, of those who bear the consequences of poor municipal services by achieving some measure of equity in both their quantitative and qualitative distributions.

In an effort to contribute towards the achievement of this goal, the research effort undertook four objectives: (1) to confront some of the issues surrounding the subject of municipal services and their distribution, to examine more closely the meaning of "equity" and to expose some of the difficulties in trying to apply certain standards of fairness to the distributive process, (2) to conceptualize the nature of the overall process which determines how municipal services are distributed among various residents in a municipality, and to model those elements in the process which create and perpetuate disparities, (3) to test the hypothesis that the negative effects of disparities fall largely upon two specific segments of the population: the powerless and the poor, and (4) to outline some strategies which might help to secure relief for the "excluded" in society and to discuss the limitations of these strategies and the implications of their successes.

The scope of this research was limited to "municipal services," a very ambiguous phrase as it is used today. Some have used the phrase literally and have allowed its meaning to continually change with the expanding roles of municipal governments and with the growing numbers and kinds of services which are provided. Thus, it is often used to connote the entire spectrum of services provided by a municipality. Others maintain that municipal services are distinct from urban services, social services, public services and other categories and include only specific types of services which relate to the physical maintenance of the city and which are primarily provided by public works departments. In any case the phrase is suffering an identity crisis and needs some helpful clarification.

In this study, the following services are typical examples of those included in the scope of research: refuse collection, the installation and maintenace of storm and sanitary sewerage, curbs and gutters; street and sidewalk surfacing and maintenance, street cleaning, snow clearing, street lighting and traffic and parking control; the provision of water for domestic use and for fire protection, the domestic utilities of electric power and gas supply; police and fire protection; and the provision of open space, recreational facilities, tree plantings and whatever other amenities for which a municipality has chosen to be responsible.

If pressed for a conceptualizing definition, the author would suggest that municipal services include all those services which are provided or regulated by a local municipality and which contribute to the quality of the immediate environment of municipal residents. The immediate environment of a municipal resident consists simply of his dwelling unit, its surrounding space, including streets, sidewalks, yards, alleys, and an agglomeration of other dwelling units. In this study it is extended to include also nearby recreational areas and open spaces, if they so exist. The focus is upon disparities in the distribution of municipal services among <u>residents</u> and, therefore, the above definition reflects this boundary. It is recognized, of course, that municipal services even as defined above are provided to commercial, industrial and public areas as well. By restricting the definition to the immediate residential and recreational environment many other services which might be provided by a municipal government are intended to be excluded from consideration here. Among these are the public services of education, health and hospital; the intangible services of planning, zoning, judication, and administration; the social services of job-training, employment centers, legal aid, welfare and other forms of income redistributive programs; and other services which are primarily intended for the commercial, industrial and other economic interests within the boundaries of a municipality. The residential environment was chosen as the focus of this study simply because it is in this environment that the greatest human suffering occurs as a result of poor or inadequate services.

Recalling the four objectives of this thesis, each was met with varying degrees of success. Chapter II documents certain instances of disparities in the distribution of municipal services, provides a more specific portrayal of the general problem of disparities, raises some of the more controversial issues and arguments surrounding the question of equity and exposes the difficulties in trying to quantify the needs of residents for services and to measure different service levels. Chapter III examines the nature of the overall distributive process and constructs a conceptual model (accompanied by a series of nine schematic diagrams resembling those used by Jay Forrester in his Urban Dynamics Model[9]) of this process from four principal sources: the author's personal observations and those of four others who participated in a ten-week summer study of municipal service systems in Cambridge, Massachusetts;[10] Gordan's research of refuse collection and street cleaning services in Boston;[11] the publications of related research efforts in the broader field of public services; and legal literature regarding the existence of disparities in the distribution of municipal services. From these sources is also drawn evidence that supports the hypothesis that those segments of the population most frequently denied adequate municipal services can indeed be characterized as powerless and poor: for those services which are provided free-of-charge and which are largely allocated by municipal officials, the powerless (meaning the politically alienated, educationally deprived and otherwise disadvantaged) are excluded by their inability to compete aggressively for their share or to resist poor quality, and for those services which are provided with service charges or user charges affixed, both the powerless and the poor are excluded by their inability to have services placed "on the market" in their neighborhoods and to resist poor quality, and by their inability to afford the direct costs of using or consuming the services. Chapter, IV, lastly, outlines several broad strategies (litigation, citizen participation and confrontation, legislation, subsidization, research and innovation) and speculates upon the consequences of their implementation.

Keeping in mind this overview and the points raised earlier, the discussion now turns to the issues surrounding the topic of this research.

II. EQUITABLE DISTRIBUTION: FACTS, ISSUES AND MEASUREMENT CONSIDERATIONS

In the Introduction it was argued that the existence of disparities in the distribution of municipal services is a problem worthy of concern and that the attainment of some measure of equity in their distribution is a goal worthy of achieving. Although one may agree in principle with both of these statements, the path towards an equitable distribution is cluttered with arguable issues and practical difficulties. This chapter serves as an introduction to many of these.

An attempt will be made first to provide a more specific understanding of the general problem and to suggest its scope by documenting certain instances of disparities in the distribution of municipal services. Then several "standards of fairness" which a municipality might use to justify these disparities are presented and discussed in order to raise the controversial issues surrounding the question of equity. And lastly, two other standards are presented which seem appropriate in light of recent court decisions, but which, unfortunately, are burdened by the difficulties of quantifying needs and measuring service levels.

A. DOCUMENTATION OF DISPARITIES

Few studies exist which specifically document unequal treatment in the provision of municipal services. Those that do, however, suggest that the problem is widespread, occurring in large urban areas and in small rural towns throughout the country, and that the magnitude of disparity can be devastatingly large.

In the small rural town of Shaw, Mississippi, even though 60 percent of the town's 2,500 residents are black, white areas monopolize the sewers, fire hydrants, water mains, sidewalks, street lights and traffic lights. A mere 3 percent of black homes front on paved streets compared with 99 percent of white homes. While the town has recently acquired a significant number of medium and high intensity mercury vapor street lighting fixtures, every one of them has been installed in white neighborhoods. Similar statistics regarding other local improvements exist and are undisputed by municipal officials.[12]

In Boston, Massachusetts, the predominantly white and middle to upper income residential area of Beacon Hill receives street cleaning services twice a week and refuse collection services three times a week during all seasons of the year. Meanwhile in another Boston district, Roxbury, a predominantly black and low income area which is equally densely populated, receives these services only once a week during most of the year, and receives refuse collection twice a week only in the summer months.[13] In Cambridge, Massachusetts, 35 percent of the city's residents receive preferential treatment in the provision of "barrel-rolling" (the rolling of refuse containers from the house to the curb) before collection, but very few of the residents in the low income Model Cities area receive this service.[14]

In Cleveland, Ohio, police provide inferior services to the predominantly Negro neighborhoods. Residents have testified, for example, that the police knowingly allow gambling and prostitution to thrive in Negro areas, but vigorously prohibit them in other areas. Cleveland police have been charged with racial discrimination in that they always investigate criminal complaints against blacks but frequently ignore those against whites. The police are also said to respond very slowly, if at all, to calls for help from predominantly black neighborhoods. An intensive study of Cleveland police records in 1965 found that the police waited on the average 50 percent longer from the time of receiving a call for help to the time of directing a police car to respond. These times for the predominantly black 5th district were averaged at 13.69 minutes, but were averaged at 8.49 and 9.27 minutes for the predominantly white 1st and 2nd districts respectively. In response to robbery calls the police took more than four times as long in the 5th district as in the other two.[15]

Fragmentary evidence supports the widely-held belief that cities do not maintain streets, sidewalks and sewers equally in their different neighborhoods. Citizens in Shaw and Itta Bena allege that each town repairs and maintains the streets and sidewalks in its white neighborhoods, but refuses to do so in its black areas.[16] In Cambridge, officials claim that sewer catch basins are cleaned out at least once every three years, but evidence shows that some basins in a low-income area had not been cleaned out in nine years despite complaints of flooding.[17] The Boston Sunday Globe reports more streets are in bad condition in the Roxbury and South Dorchester sections than in other neighborhoods.[18]

One investigation of a major midwestern city revealed that certain high income areas had more than eleven times the amount of public recreational space available for each 10,000 people than certain low income neighborhoods.[19] And Boston has been accused of providing less adequate staffing for its playgrounds in Roxbury than in other areas.[20]

B. STANDARDS BY WHICH TO MEASURE EQUITY

The pattern of disparities in the distribution of municipal services described above does not appear to be simply a matter of chance. Instead, cities appear to provide inferior services to the poor and the racial minorities. In view of the evidence, one would conclude that such treatment on the part of local government is inequitable. But how does on arrive at this conclusion? What standards are being implicitly applied to the evidence in the process of deciding what is equitable and what is not?

In the case of Shaw, Mississippi, one might feel that an equitable distribution of local improvements would be one in which equal or similar percentages of black and white homes fronted on paved streets, received sanitary sewerage and so on. Another might feel that a measure of equity would be equal per capita expenditures on local improvements in each area. A third person might feel that these standards are inappropriate and suggest that local improvements should be distributed in accordance with property valuations or with the amount of taxes each property owner paid.

In the case of the Cleveland police, one might argue that equal response times to calls for help from all neighborhoods would be equitable; another might counter by noting that the number of calls in the 5th district is much greater than in the other districts, and that 50 percent greater time delays are in fact reasonable when one considers the pressures under which the department is working. In Boston, one neighborhood receives three times the refuse collection frequency of another, and this is felt to be inequitable; but in New York City, ghetto areas receive two times the refuse collection frequency of other areas, and this is not felt to be inequitable. The higher frequency, it is argued, reflects the greater needs of the ghetto area, and so on.

Clearly, many different standards are being applied in these arguments about what is equitable. Out of this discussion should emerge the realization that the meaning of equity is subject to vastly different interpretations among different individuals and that the "standard" which one chooses to apply is simply an instrument which one uses in a debate to defend a certain value position. As such, each standard seems in reality to be little better than another.

This realization precipitates two philosophical approaches to the problem of disparities. One is an "amoral" approach. The philosophy of this approach holds that a certain distribution of municipal services is neither right nor wrong, that the allocation of services is not a process which can be subjected to arguments and compromise, but a process which must be coerced with pressure, influence and power to provide better services to the disadvantaged. The second is the "legal" approach. The philosophy of this approach holds that there are, indeed, standards of fairness which are prevalent in society, that these have been internalized and institutionalized by society in the form of readily cognizable principles embodied in law, and that these can be applied with success to the processes of distribution. In truth, each approach has merit and need not be pursued exclusively from the other. Although numerous strategies might be envisioned at this point, they will not be discussed or analyzed here, but in Chapter IV after the distributive process as a whole has been examined and conceptualized in Chapter III.

Instead, the author wishes here to play out further some of the various explanations which might be arguable in a court of law, if one were to elect the strategy of litigation, in order to raise explicitly the controversies surrounding the question of equity and to expose the practical difficulties inherent in the problem of measuring disparities. It should be acknowledged that the author has borrowed most of the legal insights which appear below from the works of others in the fields of civil rights, civil liberties and poverty law.[21]

In reality, it is highly unlikely that a city distributes its municipal services according to any consciously applied standard. Instead the patterns of quantitative and qualitative distributions develop deep within the complex structure of municipal bureaucracy, and the sociocultural and economic forces and unarticulated biases operate, if at all, only implicitly. In a court of law, however, a municipality will be asked to explain, in terms of some reasonable and acceptable standard, why disparities exist.

One explanation which might be offered is that the differential distribution is the result of historical and traditional practices, and its rationality is based on the theory that the duration of any practice for long periods of time carries with it its own approval. But in the light of a recent ruling by the Fifth Circuit Court of Appeals in Hawkins v. Shaw,[22] this explanation appears to be unacceptable. Even though the Town of Shaw claims that it now provides municipal services equally to all new developments, black and white, the court ruled that such a policy was not sufficient to justify disparities when the effect of such a policy is to "freeze in" the results of past discrimination.

Another standard which might be used to justify the existence of disparities between upper income and lower income neighborhoods, is that of "municipal taxes paid." The racial minorities and the poor pay fewer municipal taxes than the rest of the populace, and there may be some feeling among courts and city officials that those who pay less should receive less. On the surface, at least, this argument seems plausible. The city would claim that its legitimate purpose is to dispense services in a business-like manner, charging people for what they get, or giving people what they pay for. Furthermore, the city might argue that such a method of distribution would be eminently "fair" to the taxpayer. It is clear, for example, that some services are charged for, such as the utilities, on a "user fee" basis. But since other services may not be so amenable to service charging, because they cannot be quantified so easily, because the administrative expenses for billing would be excessive and other reasons, the city might argue that it can rightfully approximate the "user-fee" model by assessing general taxes of all residents and then distributing services accordingly.

Although this standard has yet to be challenged in the courts, there are several arguments which can be offered in refutation. The main argument is that the purpose of municipal government is not to provide services in a market-like manner. If it were, presumably, it would then have left the provision of police and fire protection, street maintenance, refuse collection and other services to private enterprise. Instead, the city evidently concluded that the market mechanism would be inadequate to satisfy societal and individual needs and, therefore, undertook to satisfy these needs itself. If citizens paid individually for police and fire protection, for example, only the wealthier neighborhoods would be protected from crime and fire, and the city as a whole would face increased danger to life and property. Another argument is that a municipality has an obligation to provide at least the more important municipal services to residents without regard to their abilities to pay.[23] If a city distributes municipal services according to the taxes-paid standard, it is in reality distributing these services according to whatever standard it uses to assess taxes. But taxes are assessed according to wealth, income or the amount of goods purchased, and these standards, like race, color, creed and national origin, are not acceptable as a basis for the distribution of municipal services.

Still another reason which might be offered by a local government to justify the existence of unequal treatment is that services should be distributed according to property values. For some services, such as refuse collection, street paving and repair, the provision of recreational space and others, this standard would not apply because the provision of these directly affects people and not property. However, for other services, such as police and fire protection, this standard may be appropriate because among the objectives of these services is the protection of property. Reasonably, it might be argued that higher property values demand proportionally more protection. But the loss of property could be measured in other terms than dollars. It could be measured, as well, in terms of the effects upon the people who suffer the loss, and these might be greater for the poor than for the rich if the same absolute value of property were lost. This argument, however, would be rather difficult to apply.

There are other arguments which might be presented by a city in defense of its actions, but the discussion now turns to the standards and arguments which an advocate of more equal treatment might attempt to apply.

One such standard is embodied in the notion that municipal governments should try to meet the needs of all residents equally, if not fully. Under the "needs" standard, if it could be shown that the needs of different residents are identical for some services, then equitable treatment would dictate equal service levels. Thus, in Shaw, Mississippi, for example, it is doubtful that the city could argue successfully that the needs of the poor blacks for streetlights, sidewalks, sewers and other local improvements were any different than those of whites, and thus, under this standard, the city would be required to provide equal services. However, in the cases of other services, the needs of different residents often vary considerably with sociocultural and economic conditions of their neighborhoods. A study by Benson and Lund (see Appendix A) documents clearly that the poor have greater needs for sanitation related services, remedial and health services, and police protection. Similarly, the more affluent exhibit greater preferences for other services, such as libraries, supervised recreation and other "developmental services," as evidenced by their greater participation in the use of these services. Accordingly, the government should try to satisfy all needs and preferences to an equal degree.

Clearly, there are monumental difficulties in applying such a scheme. One difficulty is that it requires the determination of "needs." In the cases where it is argued that the needs of residents are identical, there may be little problem; but in the cases where needs are variable, as for refuse collection, the task of defining needs and determining the level of service needed is ambiguous at best. In theory, the determination of the level of service needed in an area might be made by examining the varying severity of the consequences and negative effects which would result from different levels of service. Thus, for example, the minimum level of service needed for refuse collection could be determined by the maximum level of negative consequences acceptable or tolerable by the municipality as a whole. The negative consequences, in this case, might be varying degrees of accumulation of garbage and its duration, the breeding of rats and the spread of disease. It is further suggested that this maximum tolerable level of negative consequences should be subjected to a consistent and municipal-wide standard. Actually, service needs of residents appear to be determined in the "real world" in much the same way, with one exception--the standard seems to vary with different neighborhoods and is often set by a political rather than a rational process.

Here, the problems of determining service needs for certain areas of a town are, presumably, much like the problems of determining the nutritional needs for a family of four. In the latter case, after much study of the consequences of various degrees of malnutrition, a "minimum standard" was announced for nutritional needs. Implied by this standard was the notion that the nation could not tolerate, in these times of food surplus, the consequences and suffering borne by those who could not afford to eat properly.

Similarly, it is suggested that municipal service needs can be measured against a municipal-wide "minimum standard" for environmental quality. Thus, the level of service needed for pest control might be determined by the tolerable standard for rat bites per thousand children, for police protection--by crime rates, for sewer provision and maintenance --by storm flooding and water-borne disease, for street surfacing and repair--by mud and potholes, and so on.

The question remaining is how is this minimum standard defined? For the purposes of measuring disparities, this standard can be considered as having been already defined by the municipal government. The minimum standard is simply that standard applied to the "best" neighborhoods as indicated by the service levels provided to that area. If this standard appears to be excessively high for the municipality at large, then perhaps municipal officials should re-evaluate the "needs" of these areas.

The essence of this scheme for determining service needs simply suggests that all residents are entitled to reasonable municipal effort to provide equal environmental quality. One weakness of this approach, besides the practical difficulties of implementing it, is that it assumes wrongly that the municipality is entirely responsible for the environmental conditions in a neighborhood. Certainly, in some cases, the residents themselves are more responsible for the cleanliness of a street than is the municipal street sweeper. Another weakness of this scheme is that it assumes wrongly that a municipality could equalize the environment if it so desired. Clearly, it is feasibly impossible, for example, to reduce crime rates in ghetto areas to the levels of those in suburban districts. Nevertheless, in cases where gross disparities exist, it might be argued successfully in a court of law that a municipality is not doing enough to equalize the environment, presuming, of course, that the court accepts the equal environment premise.

In view of the somewhat tenuous arguments in the above scheme for determining a standard by which services should be distributed, another standard is proposed. Rather than focussing upon the "outputs" of a service, as measured by the pertinent environmental quality variables, it is suggested that a standard which focusses upon "inputs" might be equally beneficial to the disadvantaged and more feasible to implement. Thus, one might wish to argue that "equal inputs per capita," the "pro-rata" standard, is an appropriate means by which to measure equity. This standard is simply an articulation of an apparently legitimate governmental goal: the city desires, legitimately, to give each citizen an "equal share" of municipal services; it does so, rationally, by applying the principle of per capita distribution. In most instances, excepting those which concern services provided in response to varying needs, the disadvantaged would do well to achieve equal inputs. Even so, however, the use of inputs (most commonly expressed in terms of per capita expenditures) as measures of outputs is vulnerable to several criticisms, and these are briefly enumerated below.

The assumption that inputs are suitable measures for outputs is based upon the following premise: that the outputs of a service can be thought of as products of a consistent production-delivery system such that when equal amounts of resources are input into this system, it behaves uniformly to produce equal outputs. If this premise is valid for the service in question, then inputs are presumed valid indicators. Unfortunately, this premise is often invalid and the use of per capita expenditure data should be approached with caution.

One weakness of per capita expenditure data is that it leaves the quality variables uncontrolled. Per capita expenditures for a service are calculated using the total expenditure spent on one area over a given time period and the total population of that area. However, total expenditure figures disguise differences in the quality of the service. A local government may spend the same amount of money to provide the same service to two areas with the same number of people and achieve an "outstanding" quality rating by some objective standard in one area but a "poor" quality rating by the same standard in the other area. This weakness in the use of inputs was very well illustrated by Ridley and Simon[24] in the following quip:

> Suppose someone said to you, "I'm a very good shopper. I spend only five dollars today." Your reply would be, "That's all very well and good, but what did you get for the five dollars?"

Thus, the use of per capita expenditure data, by neglecting quality considerations, could yield incomplete, inaccurate and misleading data about the true level of service provided to an area.

Another weakness is that often aggregate expenditures are used rather than expenditures for each particular functional service. Obviously, the use of aggregate expenditures, besides suffering from the malady mentioned above, obscures the relationship between a specific service and the population.

A third weakness is that per capita expenditure data ignores the effects of variations in population densities between two areas. Studies indicate that the cost per unit of output of municipal services rises with increases in population and land use densities.[25] This then implies that even though per capita expenditures for two areas may be equal, one area could be greatly underserviced in comparison with the other if it were denser. Despite these weaknesses, however, the "pro rata" input standard has three advantages: it is easier to implement than the "needs" standard, in most cases it would improve the condition of the impoverished if it was applied, and it is an acceptable standard in the courts of law.

In summary, this chapter began with the documentation of several cases of apparent disparities in the distribution of municipal services. As a sampling, these cases suggested that the scope of the problem is widespread, with disparities occurring in large cities and small towns, and that the magnitudes of some disparities can be devastatingly large. In the debate over the question of what is equitable, two philosophical approaches to the problem of disparities emerged. One suggested that an agreement upon the meaning of equity was irrelevant to the real problem, and that efforts should be focussed on other strategies; the second embodied the hope that the distributive process could be subjected to the rule of law. In theory, current constitutional principles seem to support both the "needs" standard and the "pro rata" input standard as appropriate measures of equity; but in practice, except in the most extreme cases, these appear to be difficult to apply and relatively ineffective. Thus, perhaps other strategies offer more hope. Before one can talk sensibly about other strategies, however, one must first understand the nature of the process which distributes municipal services.

III. CONCEPTUALIZATION OF THE DISTRIBUTIVE PROCESS

This chapter discusses the nature of the "process" which determines how municipal services are distributed among the various residents of a municipality and attempts to conceptualize and model the important elements of this process and their interactions in a general but explicit way. The purposes in doing so are fourfold: (1) to provide insights and understanding into the distributive process, (2) to reasonably explain why disparities exist, (3) to lend support to the general hypothesis that poor services fall largely upon two distinct segments of the population: the powerless and the poor, and (4) to contribute to the formulation of strategies which may help to achieve more equitable distributions.

When attempting to define the "process" which determines how municipal services are distributed, the assumption that a single process even exists is, indeed, presumptuous, not to mention the assumption that it is capable of being defined. In truth, each municipal service, ranging from such necessities as water supply and fire protection to the amenities of tree planting and open space, is allocated and provided in a different manner and the various factors influencing the distributive process for each service are likewise different. Moreover, the patterns of distribution for each service vary with each city and town that one examines, and each pattern depends upon numerous and often unique variables ranging from the levels of municipal policies to those of personal relationships. This diversity and complexity inherent in the way in which services are distributed does not lend itself easily to generalities or to conceptualization.

Thus it is important to recognize that a general model, although perhaps useful in understanding the broader issues and in answering some of the questions posed in this study, compromises fine resolution and some accuracy. While the conceptualization may seem credible and insightful when one is subconsciously thinking "municipal services," it may seem somewhat strained in places if one tries to superimpose it upon one municipal service in particular. Bearing this in mind, the discussion turns first to an overview and later to several more detailed analyses of the distributive process.

A. AN OVERVIEW OF THE DISTRIBUTIVE PROCESS

The conceptualization begins at an elementary level by envisioning in one large set all the municipal services for which a municipal government has chosen to be responsible. The policy-level decisions of whether or not to provide a particular service and, if so, at what level of funding, bear directly upon the question of distribution. They not only determine which needs shall be met and by how much, but also dictate the climate in which all other variables in the distributive process will operate. As such, it is insightful to mention some of the reasons why a local government might want to provide a service in the first place and some of the considerations which bear upon the question of funding.

Most commonly, a municipal service is provided by local government because there is an important need for it or substantial numbers of residents want it, but it cannot be obtained by other means. The public sector provides a service because the private sector does not. The reasons for this phenomenum are several: a service may be unprofitable; it may not be amenable to service charging because of the problems with pricing, administrating and bill collecting; or it may be undesirable to provide services in an environment of profit maximization when the goal should be to maximize the public welfare; lastly, it may be societally inefficient. Private competition in the provision of some municipal services, especially the utilities, would require duplications of large capital investments and could inhibit the exploitation of economies of scale. Thus, economic considerations dictate the need for public or publicly regulated monopolies.

Although there may be several reasons why local government should provide a service, there are other considerations which weigh in the decision processes and among the most important of these concern financing. This discussion does not intend to elaborate here upon the intricacies of public finance but wishes only to make one point relating fiscal pressure and the costs of municipal services to the distribution of municipal services. Today these issues are becoming more and more the determining factors in the decisions of what services to provide and at what levels. In the face of skyrocketing costs, increasing demands for more and better services, rising expectations amid a growing population and lagging resources, municipal governments are finding not only that they cannot afford new or expanded services but that they must in fact reduce the service levels which they are now providing. If one accepts as valid the hypothesis that inadequate services fall largely upon the powerless in society, then the implications of such actions are unfortunate. Reductions in service levels would fall in greater proportions upon those least able to resist them, and disparities would be perpetuated to an even greater extreme. Although it is inaccurate to say that the disadvantaged are necessarily better off in times of less fiscal pressure, it is fair to say that strategies which aim towards the relief of fiscal pressure can have much impact upon the distribution of municipal services if used in conjunction with others which aim towards empowering the powerless. Having introduced this point, the conceptualization of the distributive process continues.

All municipal services for which a municipality has chosen to be responsible can be categorized in two ways: those which are amenable to service charging and those which are not. Although it is readily admitted that nearly every municipal service may be capable of some kind of direct assessment scheme which then can be imposed upon the recipients of service benefits, many are not necessarily amenable to service charging. To illustrate this distinction some examples are provided.

Public utilities are perhaps the best examples of municipal services which are both capable of and amenable to service charging. Benefit spillovers are minimal, that is, benefits are distinctly conferred upon subscribers; the "basic output unit" is easily quantifiable and capable of pricing; the degree of administrative sophistication which is required to operate and manage such services is considerable but entirely feasible; and the problems of metering, bill collecting and enforcement are relatively easy to overcome. Services such as refuse collection, sewer facilities and those commonly referred to as "local improvements" (street lighting, sidewalks and curbing, street surfacing and repair, street cleaning and others) are examples which are capable of but somewhat less amenable to service charging. Benefits are not distinctly conferred upon individuals but to all who may live in the area and to those who pass through. Although the basic output unit may be easily identifiable, it is somewhat difficult to price, and bill collection and enforcement problems are complicated. Nevertheless, many of these services are provided with service charges affixed, depending upon municipal policies. Police and fire protection services may be capable of service charging (witness the Pinkertons, Brinks guards and others), but are not amenable to such a practice nor would it be desirable for them to be. The benefits of police protection, for example, are perceived societally rather than individually, and the basic output unit is confused by the multiple objectives of having a police force. Lastly, it would be foolish to endanger all citizens by allowing crime to thrive or fires to roar in the areas and homes of non-subscribers. Thus, for a number of reasons, services may be categorized as amenable to service charging or not.

Of those that are, municipal policies on service charging determine whether or not a charge will in fact be placed upon a service. Rather than speculating in a few short paragraphs on how certain policies have come about or why they vary so greatly from city to city, the discussion wishes only to again point out the potential significance of fiscal pressure on the distributive process as it bears here upon the policies which determine whether or not a service will be provided "free-of-charge" or for a fee.

Today most urban areas do not directly assess residents for such services as refuse collection, sewer provision, street lights, sidewalks and many others. Nevertheless, service charging for these is indeed feasible as evidenced by the experiences of cities and towns across the country. Admittedly, this practice is more prevalent in the rural and suburban municipalities where low densities allow easy identification of the principal benefactors of the service and where initial per capita outlays of capital are much higher than in the more densely populated areas. But there are also cases where service charging for refuse collection and sewer services is the practice in dense urban areas. Atlanta, Oakland, Seattle, Rochester and Houston are examples.[26]

In light of these, the following arguments emerge. Economists[27] (Dick Netzer, Wilbur Thompson, and Samuel Wright, to name a few) and engineers[28] have all argued that the property tax is obsolete as a means of financing such services, and that service charging could provide financially burdened governments with new and significant sources of revenue. Fueling this argument, furthermore, is the fact that the costs of municipal services in general loom ominously in the background of public finance, and these in particular contribute significantly to the overall costs.

Nationally, fully one-third of all municipal expenditure is spent on municipal services. From the 1970 Municipal Yearbook, total expenditures amounted to more than 27 billion dollars (fiscal year 1967-1968) of which 12.6 billion or 47 percent were spent in the categories shown in Table 1 From the U. S. Bureau of the Census for fiscal year 1964-1965 per capita expenditure data reveals that 32 percent of urban budgets were spent in those categories shown in Table 2. Lastly, a detailed enumeration of expenditures in Cambridge in 1970 revealed that 35 percent was spent on municipal services listed in Table 3. In the ten years between 1960 and 1970 local public works departments' budgets have increased nationally at the rate of 9 percent a year,[29] and these departments provide most of those services which are amenable to service charging but which are usually provided free-of-charge.

Atthough it is difficult to say how much fiscal relief might be achieved by charging for services, it is fair to say that the argument is tempting to municipal officials. But to achieve fiscal relief by shifting service charging policies in this case would be unfortunate for the poor. The lower classes may now enjoy some redistributive benefits of the general tax, however slight they may be, through the provision of free sanitation and local improvement services. Strategies aimed at achieving a more equitable distribution under such circumstances might increment these benefits even more. But if in the future these services are provided for a fee, the poor would either have to pay out a larger percentage of their incomes for them or be denied them economically.

Table 1

National Summary of Municipal Expenditure for 1967-1968[30]

Category (and percentage of total expenditure)	Expenditure (in millions of dollars)
Education (12.7)	3,405
Public Welfare (6.5)	1,739
Health and Hospitals (5.7)	1,541
Municipal Services (46.5):	
Police Protection (8.4)	2,261
Fire Protection (5.2)	1,400
Highways (7.9)	2,142
Sanitation (7.6)	2,051
Parks and Recreation (3.8)	1,003
Water Supply (7.1)	1,928
Gas Supply (0.8)	212
Electric Power (5.8)	1,571
Interest on General Debt (3.0)	817
General Control (2.2)	592
Other Direct Expenditure	6,345
TOTAL	27,007

Table 2

Per Capita Expenditures of All Local Governments in the Thirty-eight Largest SMSA's, 1964-1965[31]

Category (and percentage of total expenditure)	Per Capita Expenditure (dollars)
Education (37.0)	123.65
Public Welfare (7.5)	25.13
Health and Hospitals (5.4)	18.17
Municipal Services (32.0):	
Police Protection (5.2)	17.27
Fire Protection (2.9)	9.87
Highways (5.9)	19.85
Sanitation (4.9)	16.54
Parks and Recreation (2.7)	9.04
Water Supply (4.6)	15.34
Other Utilities (5.7)	19.22
Interest on General Debt (3.4)	11.54
General Control (2.2)	7.27
Other Direct Expenditure	42.87
TOTAL	335.76

Table 3

City Expenditure for Municipal Services in Cambridge, 1970
(Total city expenditure was $42,254,867)[32]

Category	Expenditure
Public Works Operations[33]	3,399,435
Snow clearing, street sweeping, sewer and catch basin cleaning, park maintenance, pest control, cemetary operation, street paving and repairs, signing, equipment and vehicle maintenance and solid waste system operation (80-90% of these costs are for collection)	
Building and Housing Inspection	121,843
Electrical Inspection	271,187
Street Lighting and Traffic Signals (Electricity)	422,873
Traffic and Parking	428,960
Recreation--Golf	50,925
Recreation--Playgrounds	547,569
Police Protection (including Civil Defense)	2,902,802
Fire Protection	3,416,333
Street Construction	42,150
Gypsy Moth and Dutch Elm	7,500
Dog Officer	9,570
Capital Improvements Program	
Urban Beautification--1970	220,000
Tennis Court Program	6,000
Planting Program	10,000
Traffic Signals (Cost and Installation)	107,000
Police Vehicle Replacement	25,000
Lexington Avenue Fire Station	2,000
Public Works Coordination Study	35,000
Central Square Parking Garage	30,000
Capital Improvements Revolving Fund	45,000
Water Department	1,816,078
Total Expenditure for Municipal Services	13,917,255
Non Contributory Pensions directly attributed to the above categories	1,023,409
TOTAL	14,940,664

Once again it is pointed out that fiscal pressure and the costs of services bear upon the distributive process, as in this case by means of municipal policies on service charging.

As noted above, municipal services are now conceptualized as being divided into two more categories: those which are provided free-of-charge and those which are not. This distinction in the way services are to be rendered is obviously important to the question of how services are distributed. In the case where services are provided out of general revenues, the pattern of distribution is largely influenced by the discretion of municipal officials, administrators and supervisors, but in the latter case the pattern of distribution is more influenced by the willingness and ability of each resident to purchase them. Also, there are legal and ethical differences which should be recognized. Free services may be considered to be entitlements of all residents regardless of social or economic status, but purchased services may be considered to be privileges for only those able to pay for them.

Thus, to complete the overview, municipal services in each of these two categories enter a distributive process, or with the reader's permission, sub-processes peculiar to the philosophy in which they are rendered. From these sub-processes, then, the quantitative and qualitative levels of services are distributed among the various residents or residential areas. This is to say, more simply, that following this overview a more detailed analysis of the ways in which both "free" and "charged" services are distributed will be presented, and that each type will be addressed separately.

At this point Figure 1 is presented as the first of nine. The purposes of these schematic diagrams are several. First, they are used both to summarize and to clarify the points made in the text. Second, they provide at a glance the various conceptualizations and their interrelationships which have been made elsewhere. But more importantly, they are the results of an experiment in understanding. From the beginning of this research, the "process" which distributed municipal services seemed to be studded with confusing and circular interactions and to be influenced throughout by forces which seemed to hold a certain distributive pattern in a state of "equilibrium." The level of service actually provided to an area, for example, seemed to be a function of the level of service tolerated by the residents in the area. But this was in turn a function of past service levels. But cases of increased resident pressure were inconclusive--sometimes this worked and other times it did not. Political pressure was shown to be a positive force in some cases for obtaining better services, but a depressing force in others if improved services started an immigration of more affluent residents due to the increased intra-city attractiveness. Strategies toward equitable distribution, if applied singularly, seemed to hold out little hope, for the forces which had created unequal distributions could then manifest themselves in other ways which could neutralize any gains. Some indications showed that if strategies did in fact succeed, it was to the injury of those who were the focus of concern.

Because it was confusing to recall many general observations simultaneously and to try to interpret them in continually changing light

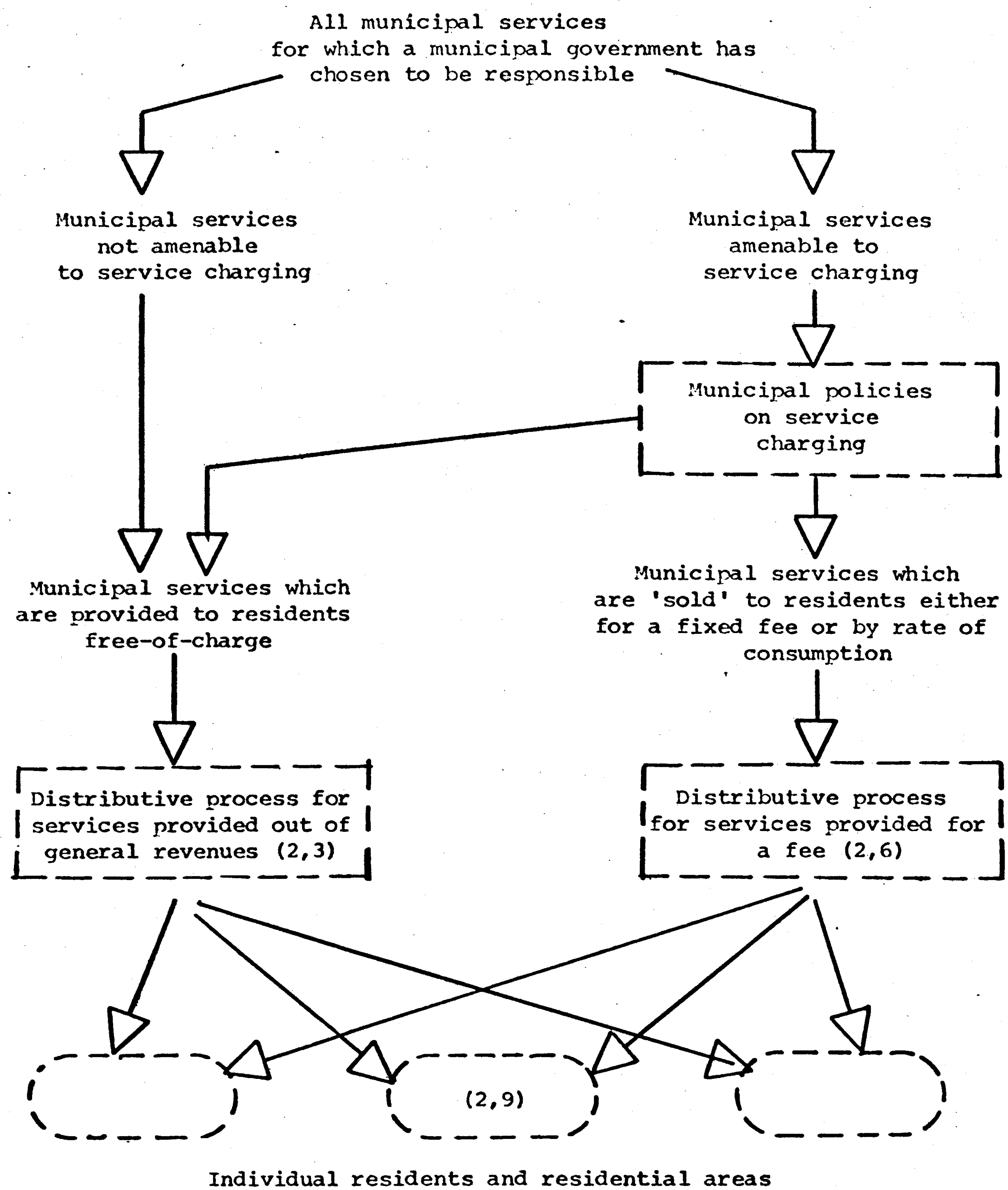


Figure 1: An Overview of the General Distributive Process

it was felt that a more explicit model of the essence of each would be useful. Heavily influenced by the various applications of "systems dynamics"[34] and by the works of Jay Forrester, these schematic diagrams are an attempt to explicate the variables and their interrelationships with the hope of better estimating the second and third order effects of particular combinations of relief strategies. Whether or not this effort has been of value is somewhat debatable and is left for the reader to decide.

Figure 1, then, simply represents the overview presented so far. In this figure, all those services for which a municipality has chosen to be responsible are, first, categorized as to whether or not they are amenable to service charging. Those which are not are, of course, rendered to the public free-of-charge. Of those which are, however, municipal policy determines whether they will be provided free-of-charge or "sold" for a fee. From here each set of services enter their respective distributive processes, or sub-processes, from which they fall upon both residents and residential areas depending upon the nature of each particular service. The numbers in parentheses in Figure 1 serve as a means of cross-referencing, and are the figure numbers of other diagrams where the referenced item is again displayed.

The existence of disparity in the distribution of municipal services, if one will recall the discussion in the previous chapter, depends more precisely upon the <u>level of service</u> provided rather than upon the quantitative amount of service provided. Two areas may receive the same amount of service, for example, and in one the service may be excellent but in the other, poor. Recognizing the importance, then, of both the quantitative and qualitative facets of the level of service variable, a general scheme illustrating this is shown in Figure 2. The allocation of service quantities and the control of service quality are modelled separately to reflect the fact that different factors may affect each. For example, municipal officials may have considerable control over the allocation of service quantities, but may have little power to effect the actual quality of service. Oppositely, municipal employees directly effect the quality of service, which often varies with different neighborhoods,[35] but may have little control over the actual allocation of service quantities.

The valve symbols inside the broke rectangular outline, as shown in the figure, are used to represent control over the flow of quantity and quality to the different areas and to distinguish these variables from others in subsequent figures. The flattened ellipse represents a recipient individual or residential area, and inside it are two solid rectangular elements representing the quantitative and qualitative levels of service provided to the recipient. Summarizing, these two initial figures simply provide the basic structure upon which is hung the essence of the process which determines how municipal services are distributed.

Bearing in mind the perspective provided in this overview, the next section focusses more narrowly upon municipal services provided free-of-charge.

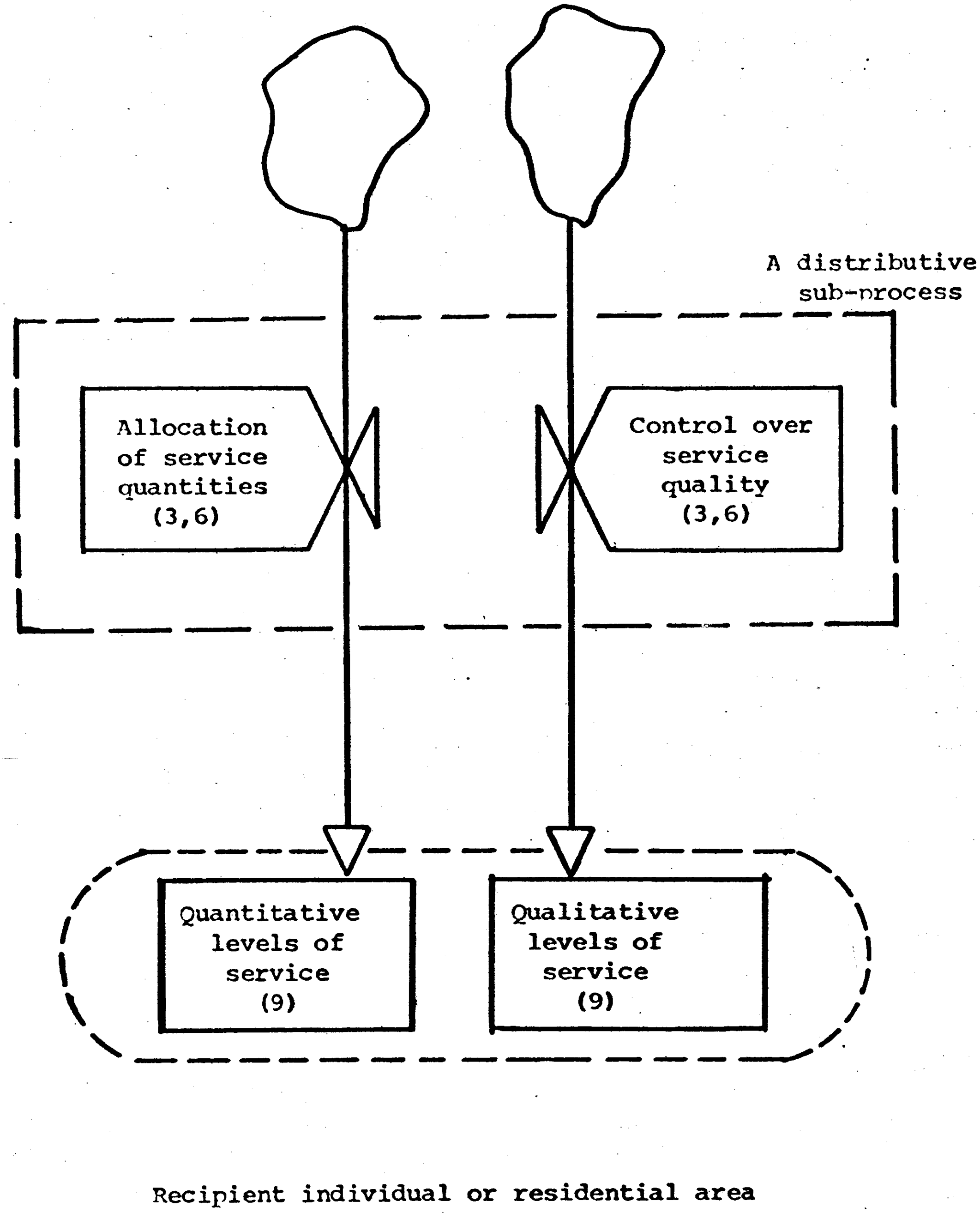


Figure 2: A Simple Schematic Diagram for a Distributive Sub-process

B. MUNICIPAL SERVICES RENDERED FREE-OF-CHARGE

At the most general level, the distributive process for those municipal services which are financed out of general revenue and which are rendered to the public free-of-charge is conceptualized as being principally influenced by three broadly categorized variables. One is the use of discretion by municipal officials, administrators, and supervisors in the daily performance of their duties and responsibilities; another includes the various effects and influences of the public employee, organized or otherwise, as he manifests his own attitudes and self-interests, and as he plays an expanding role in the making of policy and its implementation; and a third includes a host of other factors lumped together under the term "exogenous inputs."

This third category contains such factors as the costs of providing services, overall budget constraints, municipal guidelines for the allocation of services, legal mandates outlining municipal responsibilities, the kind of organizational structure of the local government and others. They are labelled "exogenous" in this study because they are condidered as the overall constraints within which the other variables of the distributive process are free to operate.

The fact that these are exogenous inputs should in no way detract from their importance. Service costs and budget constraints, for example, are critically important to the determination of the levels of resources which are available for allocation, and these weigh heavily in the decisions of who gets what and how much. Different kinds of organizational structures of governments may either allow considerable freedom in the use of administrative discretion or subject decision making processes to tightly controlled procedures and municipal guidelines. Furthermore, the fact that these inputs are exogenous in no way means that they are incapable of changing with time. Costs may increase, budgets may be reduced, the political climate may change, affecting the degree of centralized control, legal mandates may order different allocative procedures and other changes can be envisioned. But for the purposes of analysis these factors are considered at any one point in time as the "givens" of a specific situation.

Some of these are enumerated in Figure 3 and are shown schematically to principally influence the allocation of service quantities. As a point in notation in this figure, the broken lines appearing with arrowheads are used to represent an influence or an effect upon one element or variable in the scheme arising from another. Variables in the figure which are faced by square corners do not appear in other figures, while those which are faced by curved lines do and are modelled in greater detail. Again, the numbers in parentheses cross-reference other figures. Although the exogenous inputs may significantly affect only the quantitative allocation of services, administrative discretion (the phrase is used here in its broadest sense, meaning the discretion of personnel at all levels of administration, supervision and management) and the effects of public employees significantly affect both the allocation of service quantities and the control over service quality.

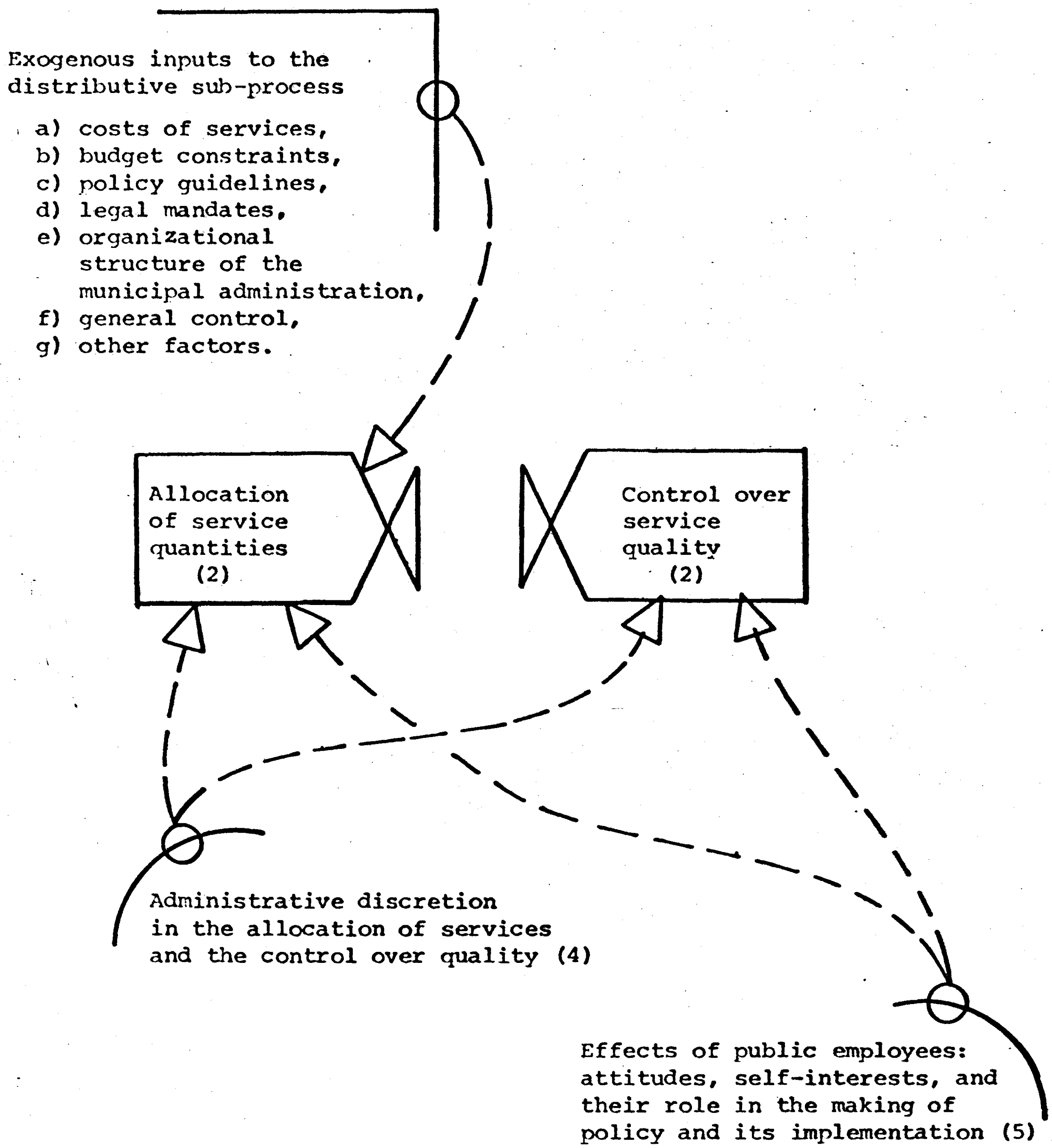


Figure 3: Variables Influencing the Distributive Sub-process for Municipal Services Rendered Free-of-charge

Administrative Discretion

Evidence indicates that administrative discretion, as it affects the distributive process, is a major, if not the most significant, variable in the creation and perpetuation of disparities. Although it affects the actual allocation of service quantities most directly, it significantly influences the distribution of service quality as well. The evidence supporting these claims is drawn from four principal sources: the author's participation in a ten-week summer study of municipal service systems in Cambridge, Massachusetts, Gordan's[36] research of refuse collection and street cleaning services in Boston, the publications of related research efforts in the field of public services, and legal literature regarding disparities in the distribution of municipal services.

Of these, the foremost is the author's Cambridge experience. This study was undertaken in the summer of 1970 and its objective was to gain insights into the operation of several specific municipal services with the hope that some facets of recent research and technological innovations might be applied to these operations. A large portion of the work during this period was spent interviewing supervisors, managers, administrators, and other municipal officials, and learning and occasionally participating in daily operations. The concluding report, Cambridge Municipal Services Study, 1970,[37] failed, somewhat, in outlining technological innovations, but the focus of the study had long since shifted. What was far more intriguing was the nature of local government, the interrelationships between agencies and between personnel, the politics of patronage and of the provision of service, the visceral decisions of municipal officials, and the ways in which assignments were actually accomplished or slowly undermined. Throughout the report appears a wealth of information and insights about the workings of one specific, and perhaps typical, local government, and especially about the ill-defined process by which municipal services are allocated among the competing residents and residential areas of Cambridge. Although the following model of the factors influencing administrative discretion purports "generality," the author's reliance upon this experience unavoidably has given it a distinctly Cambridge coloring. Nevertheless, information from other sources indicates that these insights are applicable in varying degrees to other municipalities as well.

One insight concerned the nearly limitless reign of administrative discretion in the Cambridge Department of Public Works (DPW). DPW is responsible for many of the municipal services provided by the city including refuse collection, street cleaning, snow clearing, sewer and catch basin cleaning, and others. The sound exercise of administrative discretion is, of course, unobjectionable in itself, especially when it has a rational basis and is reasonably objective in the allocation of services. Ideally, though, the amount of decision making left solely to the discretion of authorities should be curtailed whenever possible, and replaced by more analytic and explicit methods. The tools of systems analysis, information systems and Planning, Programming and Budgeting System (PPBS) are examples of some of the recent developments toward administrative sophistication which would greatly improve the efficacy of municipal service systems. All the available literature suggests, however, that municipal agencies (with the exception of some in New York City) rarely find themselves in the vanguard of administrative innovation. Those in Cambridge are typical at best. Furthermore, the operational organization of the Cambridge Administration, although appearing in theory to be centralized beneath the city manager, was in reality fairly decentralized under City Manager John Corcoran, with each department running its own show. Thus, in the void of sophisticated analytic and methodological techniques, and with loose administrative control, middle level officials were allowed a maximum of freedom in exercising their best judgements.

When discretion is exercised, hopefully it relies upon factual information. In Cambridge, there is an ubiquitous dearth of factual information. The only records which were maintained in the offices of DPW were personnel records: salaries, wages, overtime, sick leave, vacation leave and other data. Nowhere could it be determined where a service had been provided, when or at what frequency or how much had been provided. There was no routing plan for street sweeping, and the streets which were cleaned were apparently chosen in an arbitrary way. Don Zollo and Larry Frazier of the Environmental and Municipal Services Component of Cambridge Model Cities agreed that "some streets [in the Model Neighborhood Area] had never been swept."

Poor management of DPW is one reason for the poor service and the lack of information. Of the three sweepers that DPW had, never during the ten weeks of study was there more than one operable, and the odometer, which might have yielded clues as to its use, was broken. There was no weighing of refuse collection vehicles, even after City Manager Corcoran had requested this on our behalf. There was no recent cost data except at the hopelessly aggregated level of the Annual Budget. This dearth of information can be partially attributed to the fact that nearly all of the personnel in administrative or supervisory positions have risen up through the ranks, and as such, most are unaccustomed to "paperwork" and don't see the need for data. Commissioner Ralph Dunphy, for example, seemed to spend little time in his office and, by his own admission, spends most of his day in his radio-equipped car inspecting daily operations. Nevertheless, one can hardly overlook another possible reason for this lack of data--the convenient and virtual invulnerability to challenges of inefficiency when no one knows what is going on.

This exposé is provided only to underscore the fact that administrative discretion, at least in Cambridge, often has no rational or factual basis whatsoever. Instead, nearly all decisions in DPW are heavily reliant upon intuitive models of operations, scheduling and allocation of service, and these are built largely upon experience, maxims and folklore which have accumulated over the years in spite of evidence that some portion might be incorrect. In this vacuum of information, administrative discretion is not only allowed exorbitant freedom, but is dangerously unchallengeable. In recognition of this point, the use of administrative discretion is conceptually modelled to respond to the different effects of varying degrees of respect for or reliance upon factual data, record keeping, systematic and periodic scheduling of services and inspection of serviced areas, modern management techniques, intuitive models of operations and allocation of services, past experiences, folklore and other factors.

Another insight into the way in which administrative discretion affects the distribution of municipal services, was that administrators must first perceive the needs for services before services are ever allocated. Because there is no systematic and thorough inspection of such things as sewers and streets nor any periodic scheduling of preventive maintenance, services are often provided only in response to complaints by residents who take it upon themselves to report the need for service. Thus, needs for service are often never perceived by municipal officials unless they are clearly and loudly articulated. In Cambridge, for example, it was observed that the daily job assignments for many of the DPW employees in the "labor pool" were drawn from a list of complaints from residents compiled the day before. To obtain service a resident had to phone in a request for it.

Officials in Boston's Public Works Department (PWD) readily admit the importance of the complaint. Not only does it allow administrators to perceive needs for services but it is often considered as a valid indicator of service adequacy. In the 1964 Annual Report of the Boston Public Works Department is the following statement: Under discussion is a particular type of refuse removal operation "which has proven satisfactory as evidenced by the absence of complaints from this district." Although most complaints are received by phone, officials say the most effective complaint is one that is written.

It is a well observed phenomenum that local governments tend to provide no better service than the minimum amount tolerable by the residents of an area. In a voluminous report of public services in Perry Hilltop (near Pittsburgh), Pennsylvania,[38] for example, is the following note: in the face of insufficient operating and capital funds, "the local government follows the minimum standards which the public will accept without political revolt," and then continues to cite resident apathy as a major reason for poor service. The Cambridge study and Gordan's of Boston similarly noted that the level of service provided was often a reflection of the level of service demanded. In Gordan's interviews with refuse collection contractors, one replied to a question concerning the difficulties of different districts: "West Roxbury is the toughest district. They demand the best service. If we didn't do a good job, West Roxbury is the place you'd hear from first." Lastly, at the risk of belaboring the point, in another interview she recorded the comment: "As the class of people go down, service requirements go down." Clearly, articulated demands and complaints affect both administrators' perceptions of the service needs of different areas and the way in which they allocate services and control quality.

Complaints and the threat of action are not the only weapons available to residents who are battling for better service. Residents can often exert more direct pressure upon administrators and may, themselves, have "influence at City Hall." The residents of Beacon Hill, for example, have organized themselves and are represented by the Beacon Hill Neighborhood Association. Apparently BHNA exerts significant influence upon the Boston PWD through "their representative," and it is no accident that Beacon Hill gets street cleaning twice a week when all others receive this service only once a week in Boston,[39] and that Beacon Hill gets refuse collection services three times a week in all seasons of the year while other areas in the city, equally densely populated, receive it only once or twice a week depending, in most cases, upon the season (refer to Table 4). Boston authorities admit themselves that they respond rapidly to the request of or complaints from BHNA. Influential residents can easily obtain preferential treatment for their own neighborhoods. Gordan observed the feeling among some collection crews that the worst areas to work in were "where the politicians live."[40] In an exclusive stretch of New York City's Park Avenue a bustling rat colony had suddenly been discovered and Health Department exterminators quickly appeared,[41] yet in the slums of the city millions of rats thrive under municipal indifference. Is not a rat a rat? It appears, then, that pressure from influential residents or residential association can and does bear upon the decision processes which determine who gets what, how much and of what quality.

Political pressure is yet another factor weighing upon administrators' "best judgements." The fact that Mayor Vellucci of

Table 4

Refuse Collection: Collections Per Week

Boston District	Location	Rubbish	Garbage 9/1 to 5/31	Garbage 6/1 to 8/31
1A	Charlestown	1	1	2
1B	Downtown (North & West End, Beacon Hill)	3	3	3
1C	Uptown	2	2	2
9	East Boston	1	1	1
10	Roxbury	1	1	1
2	Jamaica Plain	1	1	2
4	Brighton	1	1	2
6	West Roxbury	1	1	2
8	Hyde Park	1	1	2
3	Dorchester North	1	1	2
5	South Boston	1	1	1
7	Dorchester South	1	1	2

Source:[42] Gordan's interviews and <u>PWD Contract</u>

Cambridge happens to derive the majority of his political support from the ethnically Italian area of East Cambridge and that this neighborhood is among the "best serviced" in the city is no coincidence. "Best serviced" is used loosely. The consensus among residents with whom this author has spoken is that this area does receive better service, but the only evidence discovered supporting this feeling is the routing of snow clearance vehicles, and the only reason that these routes are actually recorded is because they are contracted in the private sector. Nearly all residential streets in East Cambridge are required by contract to be plowed, but in other areas such as Cambridgeport, only the heavily travelled arteries are designated by this priority.[43] The phenomenum of political pressure being exerted by elected representatives on behalf of their constituencies, however, needs little documentation here.

Of the major categories of factors which affect the exercising of administrative discretion, one remains to be discussed. Evidence indicates that many of the large scale disparities in the distribution of municipal services are simply the results of unarticulated biases and arbitrariness on the part of officials. Below, two cases are drawn from the author's experience in Cambridge, and one from a now famous legal suit.

In Cambridge, "barrel-rolling" is a popular service among those who receive it. On the day of refuse collection "barrel-rollers" roll the garbage and trash barrels from behind one's house to the curb before pick-up. In 1965 this service was estimated by John Corcoran, now City

Manager of Cambridge, to cost $206,000 annually, nearly one-third of total collection costs. Commissioner Dunphy estimated that 35 percent of Cambridge residents receive this service. Originally this service was intended to help the elderly and the physically handicapped who, in the days of wood and coal furnaces when ash barrels were exceptionally heavy, could not manage this task alone. Today, however, a great portion of the residents who receive barrel-rolling services do not fit into this category, evidenced by the incredibly large percentage of the population which would have to be aged or disabled, if by nothing else. When the Model Cities staff learned of the service, however, a quick survey revealed that very few of the residents in the Model Neighborhood were receiving it, even though many were eligible under the formal requirements. A short-lived effort on the part of Model Cities to organize these residents for entitlement was met with a flat refusal by DPW to provide the service.

A second case again involves the residents of the depressed Model Neighborhood Area. According to Don Zollo, head of the Municipal and Environmental Services Component of Model Cities, clogged sewers and catch basins and the resulting flooding of streets and sidewalks had been a problem for several years. Storm water would stand for days in low areas causing inconvenience and irritation to residents as well as presenting a health hazard. Allegedly, repeated complaints to DPW had brought no response, and the catch basins had remained clogged. In exasperation, he said, Model Cities hired its own equipment to do this job. Evidenced by the layers of autumn leaves in a basin's sediment, many had not been cleaned out in five to nine years. At the same time, however, DPW had equipment and crews operating in other areas of the city. Both cases indicate that complaints, requests for services and even organized residents' pressure, can be met with administrative discretion characterized by blatant arbitrariness.

Lastly, the biases which administrators may have toward certain racial, ethnic or socio-economic groups can be another force in the creation of disparities. It was this hypothesis, in fact, which Gordan was testing in her research of Boston. Among administrators, she found that some were understanding of the plight of the poor, but that others were of the opinion that the lower classes simply didn't care about neighborhood cleanliness. But a recent legal suit on behalf of the blacks in the Town of Shaw, Mississippi[44] illustrates more clearly than any other example the potentially powerful effects of administrators' biases.

As in many rural southern towns, the residential areas of Shaw were segregated. Blacks comprise 60 percent of the town's population of 2,500, yet only 3 percent live in homes fronting on paved streets while 99 percent of white homes front on paved streets. Nearly 97 percent of black homes are not served by sanitary sewers, but only 1 percent of white homes are not so served. Although the town has acquired a significant number of medium and high intensity mercury vapor street lighting, every one has been installed in white neighborhoods. Similar statistical evidence of grave disparities in both level and kinds of services offered regarding surface water drainage, water mains, fire

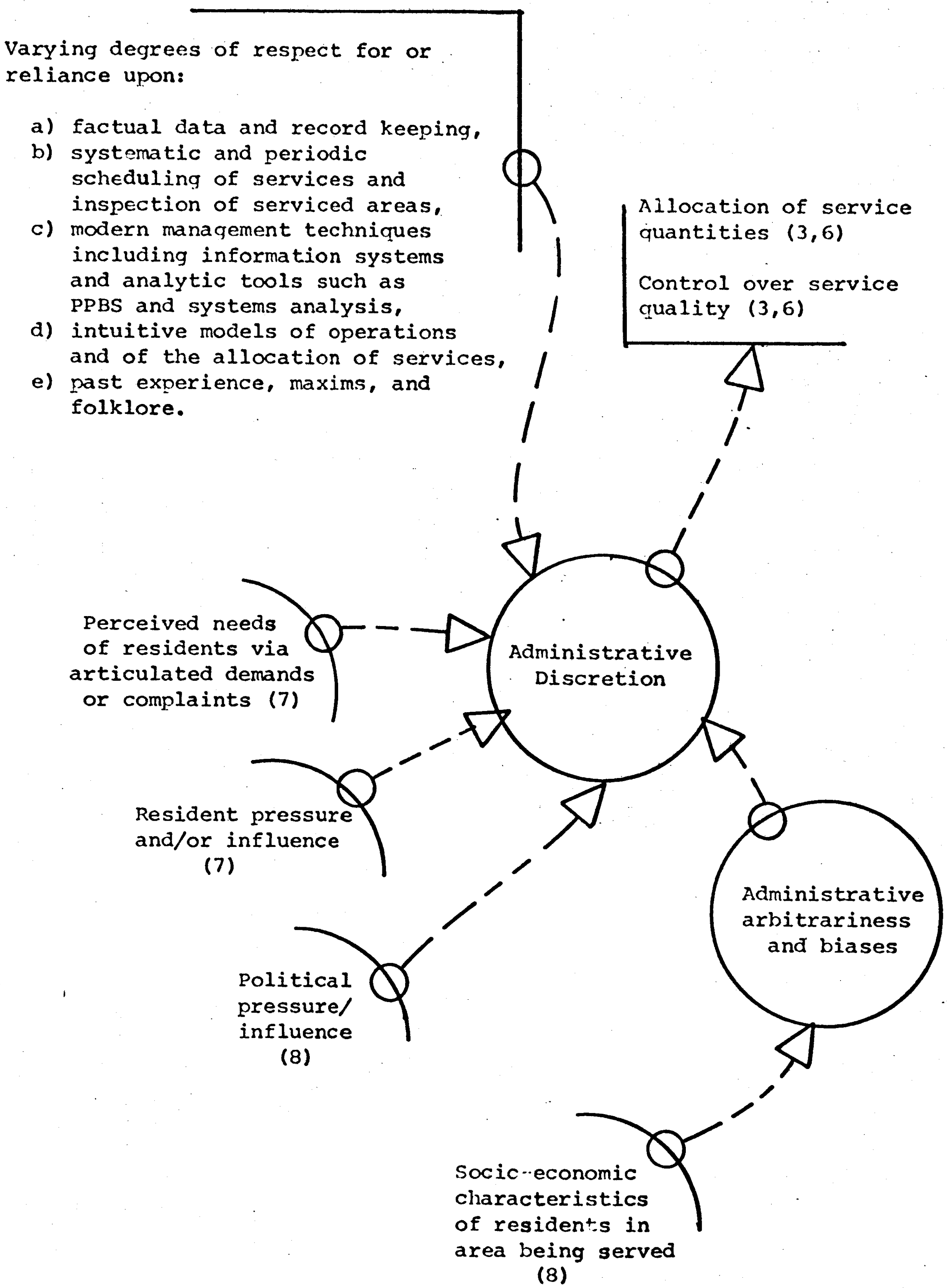


Figure 4: Factors Influencing Administrative Discretion

hydrants, and traffic control apparatus, is available and undisputed by municipal officials. The U.S. Court of Appeals for the Fifth Circuit ruled that these statistics were enough evidence to establish a prima facie case of racial discrimination.

In summary, administrative discretion appears to be a most significant variable influencing the distribution of municipal services rendered free-of-charge. Although it primarily affects the allocation of service quantities it also exerts control over service quality. There are, of course, many considerations and forces which shape its use. The above paragraphs have attempted to broadly categorize them and to enumerate and document some of them as illustrations. Schematically, these categorized factors influencing administrative discretion are displayed in Figure 4, which at this point is hopefully self-explanatory. Before elaborating how these factors tend to work against certain segments of the population, the discussion now examines briefly another variable influencing the distributive process--the effects of public employees.

Effects of Public Employees

Public employees can directly affect the distribution of municipal services. Specifically, the unarticulated biases of public employees toward certain population segments can seriously undermine the quality of the services being provided and, as such, significant disparities in the distribution of services can result simply from qualitative differences.

The fact that these biases can and often do exist needs little documentation here. Nevertheless, Gordan's interviews with men of the refuse collection and street cleaning crews brought out some comments which are worth noting:[45]

> Roxbury (a low income and predominately black area) is the "worst" section because the trash is "all on the ground." It's a dirtier and sloppier job and there are "lots of rats." People in Roxbury "have kids, but don't have proper control over them. They let them do anything. The class of people is important. These people never know nothin'. The front door could be smashed--probably the ol' man did it--and they never tell. They don't even want to help themselves." "If you clean in the morning it's dirty again at night." "As the class of people go down, service requirements go down."

All these comments suggest the service quality in certain areas is probably at a minimum level. Gordan notes that although employees deny that some areas get better service than others, they do admit that it is harder working in the upper-middle class neighborhoods "because you know you have to do a good job."

Besides being able to directly affect the distribution of services qualitatively, with the recent and accelerating trend toward unionization of public servants, employees are fast gaining the ability to affect the quantitative distribution as well. When former mayor of New York City, Robert Wagner, asked the police to patrol the housing projects, the police refused and were supported by the commissioner.[46] Organized and represented by the Patrolmen's Benevolent Association (PBA), and entrenched in the protection of the civil service merit system, the policemen are virtually invulnerable to harsh disciplining. This example is indicative of effects of unionization upon other services, too, as is discussed in an article by Francis Piven, "Militant Civil Servants in New York City."[47]

Furthermore, public employees are beginning to demand the right to set policies, usually on the ground that as the people who are actually performing the jobs, they should know what's best. The PBA has begun issuing its own instructions to policemen on how the law should be enforced, to countermand Mayor John Lindsay's presumed indulgence of looters and demonstrators. Similarly, the PBA opposed, nearly successfully, the formation of the "fourth platoon" permitting heavier scheduling of policemen during high crime hours, the formation of civilian review boards.[48]

In summary, municipal employees have always had the ability to affect the quality of services, and are now, by banding together, beginning to exercise expanding control over public agencies. Organized, they can erode quality of service in certain areas, undermine policies they don't like, and even declare and implement their own policies. In short, employees are beginning to assert their attitudes and self-interests. Unfortunately, as urban populations change in socio-economic complexion such that larger segments of the "general public" are black and poor, ethnic and ideological differences between the servants and the served become sharper, and the various effects arising from these differences may seriously affect the distribution of municipal services. It is noted here that as the effects influence services qualitatively, it makes little difference whether municipal services are rendered free-of-charge or with service charges affixed. Again these points are

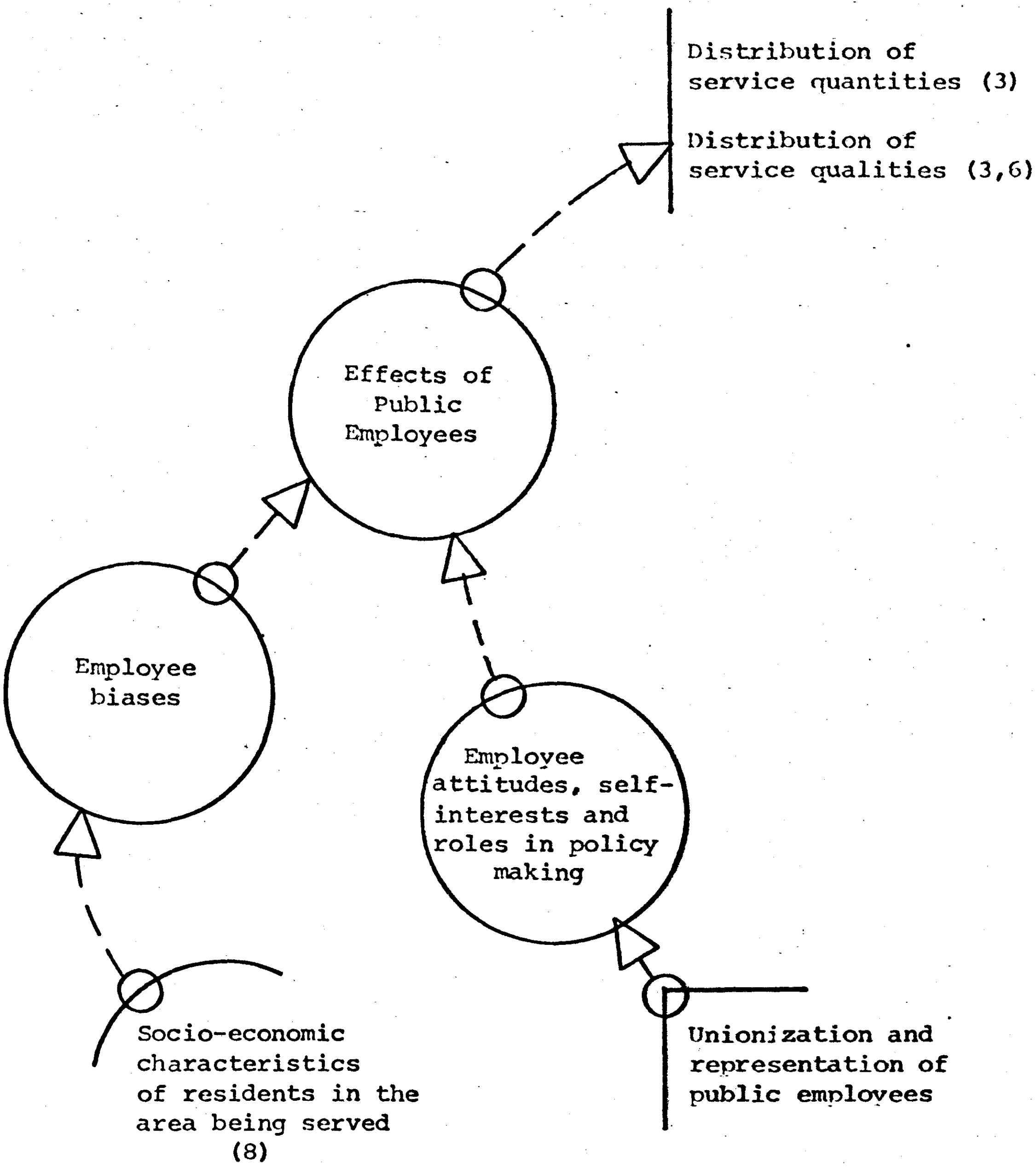


Figure 5: Effects of Public Employees

modelled schematically in Figure 5.

C. MUNICIPAL SERVICES RENDERED FOR A FEE

Although most municipal services in well-populated areas are rendered free-of-charge to the public, there are, nevertheless, many which are not. Recalling a previous enumeration, examples of these are the utilities or those services which are perhaps best described as "flow systems": water supply, electric power, gas supply and frequently sewer services. In a survey conducted by the American Public Works Association (APWA) in 1969,[49] of 454 municipalities reporting, 333 (more than 73 percent) replied that they levied sewer service charges. This charge is often based on the amount of water metered and can be greater than 100 percent of the water charge, but is usually less. The same survey revealed that 44 percent of the reporting cities levied service charges on refuse collection. Other services which are, in some areas, rendered for a fee are the "local improvements," such as street cleaning, sidewalk installation and maintenance, street lighting, tree plantings, the provision of recreational areas, and even rat and pest control services.

Although it is difficult to talk generally about all these kinds of services at once, it seems that one can conceptualize two phases of the distributive process for all of them: the first concerns the decisions of where these services are to be made available such that residents may purchase them, and then after the services have been made available, a second phase, resembling a market mechanism, takes over and determines which residents will actually receive the service because they are willing to "buy" them and who won't because they are unwilling or unable to buy them.

In the first phase, there are numerous factors influencing the decisions of where services are to be "put on the market." In the older and larger cities, the "necessary" services (utilities, refuse collection and sewer services) usually already exist in most areas to some degree or another. In the smaller and expanding municipalities, however, decisions must be made as to where these services are to be authorized and extended. For services which might be better typed by the word "amenities," regardless of city characteristics these same decisions of where services will be made available must be made. It is surmized that they would be based upon reasonable considerations, cost/benefit studies, anticipated demand and revenue, but in the end would be made at the discretion of local authorities.

It is precisely at this point where disparities may again occur, for there is no evidence to indicate that administrative discretion in this case is any different from that of before. Thus, if litigation, for example, were successful in mandating equal treatment in the Shaw, Mississippi case as long as services were provided out of general revenues, town officials could shift policies, affix service charges, reduce the tax rate accordingly and claim that the poor and Negro areas were risky investments; besides this, these low income families may not be able to afford the services anyway.

In the second phase, once and if services have been "put on the market" in an area, the distributive process is conceptualized as operating much like a regulated monopoly market mechanism. Services are dispensed in accordance with the perceived value of the services--a function of the needs and preferences of different residents--and with the abilities of residents to buy the services. Clearly, the ability to pay is a function of a resident's economic status.

In Lexington Park, Maryland, water and sewer service charges are computed from a "front foot benefit" fixed charge and a variable rate charge. If a resident owns 200 feet of front footage, these charges usually amount to well over a hundred dollars a year, and the author knows of several cases where poor residents have wanted and inquired about these services but then said they could not afford them. It is ironic that the very pipes which may be physically as close as 20 feet, are in reality so far away. It should be noted here that a strategy of subsidization would indeed be applicable in these cases.

As mentioned in the previous section, the effects of employees upon service quality are essentially identical here as for the "free" services. There is one implication, however, which is different. As service qualitv goes down, the need for service quantity usually goes up in an effort to compensate the low level of service. This might mean that the actual cost of adequate service may rise in areas where employee biases manifest themselves in poor quality.

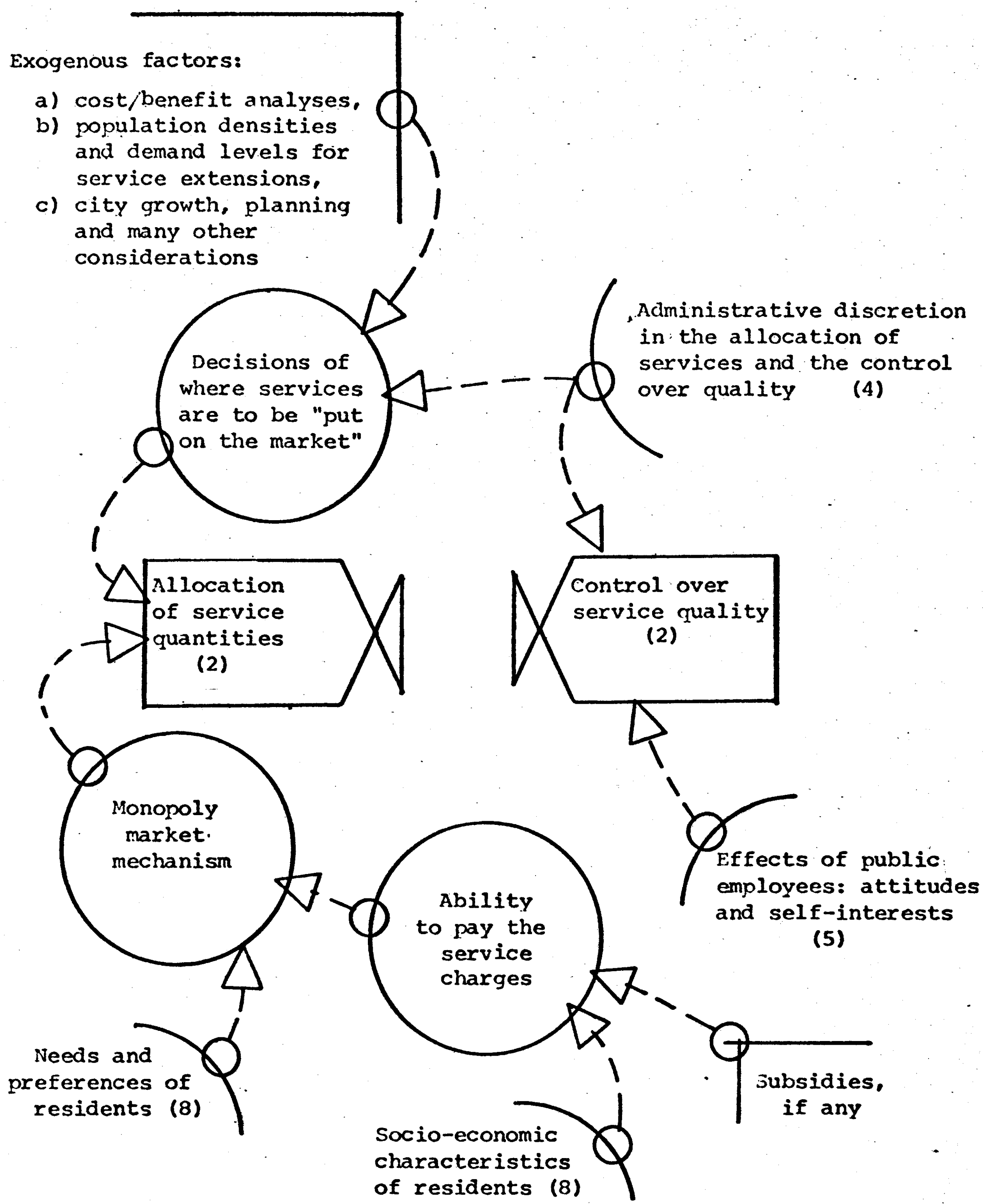


Figure 6: Variables Influencing the Distributive Sub-process for Municipal Services Provided for a Fee

In summary, the distributive process for municipal services rendered for a fee is conceptualized textually above and schematically in Figure 6.

D. EXCLUSION OF THE POWERLESS AND THE POOR

The preceding discussions have all tried to identify and document the principal forces which determine how municipal services are distributed, and to conceptualize and organize these forces and their effects in a coherent and explicit model. The discussion in this section hopes to illustrate that all of these forces, if allowed to operate freely, tend to work against the disadvantaged members in society and do so largely because they are powerless and poor.

If the observations of Cambridge, Boston and Shaw are representative of municipalities in general, then it is reasonable to assume that the internal workings of local governments are characterized by considerable freedom in the use of administrative discretion. Furthermore, unchecked discretion typically operates in an environment of average to poor management and often relies upon visceral judgements rather than upon factual information, systematic scheduling or periodic inspections.

Recall that in such an environment the needs of residents for certain levels of service are often never perceived by municipal officials unless the residents themselves clearly articulate them. It was noted, for example, that local governments facing fiscal pressure tend to provide the minimum level of service tolerable, and that the "complaint level" is often used as an indicator of service adequacy. Unfortunately, this reliance upon resident feedback distorts the true needs of different classes of people--the middle and upper classes articulate readily and effectively, the lower classes don't. The poorly educated, for example, have little skill in writing letters; the unsophisticated may be intimidated when speaking to municipal officials or, for that matter, to the sometimes terse operator at City Hall; the alienated may not know whom to call, how to complain or that complaining is worthwhile. In sharp contrast, the middle and upper classes can easily and confidently articulate their irritations and, as such, enjoy a distinct advantage over the lower classes.

Moreover, different people react differently to poor or inadequate service. In terms of the outward signs which are meaningful to municipal officials and employees alike, the rich tend to tolerate very little poor service and the poor tend to tolerate much more. Accordingly, some people receive better service than others.

There are a number of explanations for this apparent difference in toleration levels. One, as mentioned above, is that the disadvantaged are less able to express their irritations in terms of the outward signs which are meaningful to officials--the written letter, a well articulated phone call. Another is that the lower classes may be unknowing of their rights and entitlements to certain services and to service adequacy. In Cambridge, for example, many do not know that "barrel-rolling" exists or that DPW picks up bulk refuse when called. A third explanation might be that the poor are less motivated to try to obtain better service through the "proper channels." Gordan noted a consensus in her interviews with Roxbury residents that complaining was ineffective, "what good would it do to complain? They don't care about this place." Adding validity to this feeling is the observation in Cambridge that complaining was sometimes effective and other times it was not--and the distinction seemed related to sociocultural factors. Lastly, there are indeed differences in the demands and expectations of different people.

The service demands of an individual at any income level are a function of his cultural experience, his social conditioning to environmental quality variables and to past levels of service, and the attitudes and habits of other individuals within his life space. It makes little sense to complain about an unswept street when garbage lies in heaps in the alleys and vacant lots. This is not to say that the low income person is not concerned about poor environmental quality, but suggests that he may be consigned to it by the state of his condition and by his powerlessness in general. (Because these points relate directly to those modelled conceptually in other sections, they are similarly modelled in Figure 7.)

The positive benefits of political representation need no elaboration here. Surprisingly, however, there are possible disbenefits. A politician who understands the needs and preferences of his constituents will presumably act upon these in a positive manner as long as he perceives that such actions do not endanger his political base. In an interview with Justin Gray, past head of the Community Development Section of the Cambridge government, it was noted, however, that often

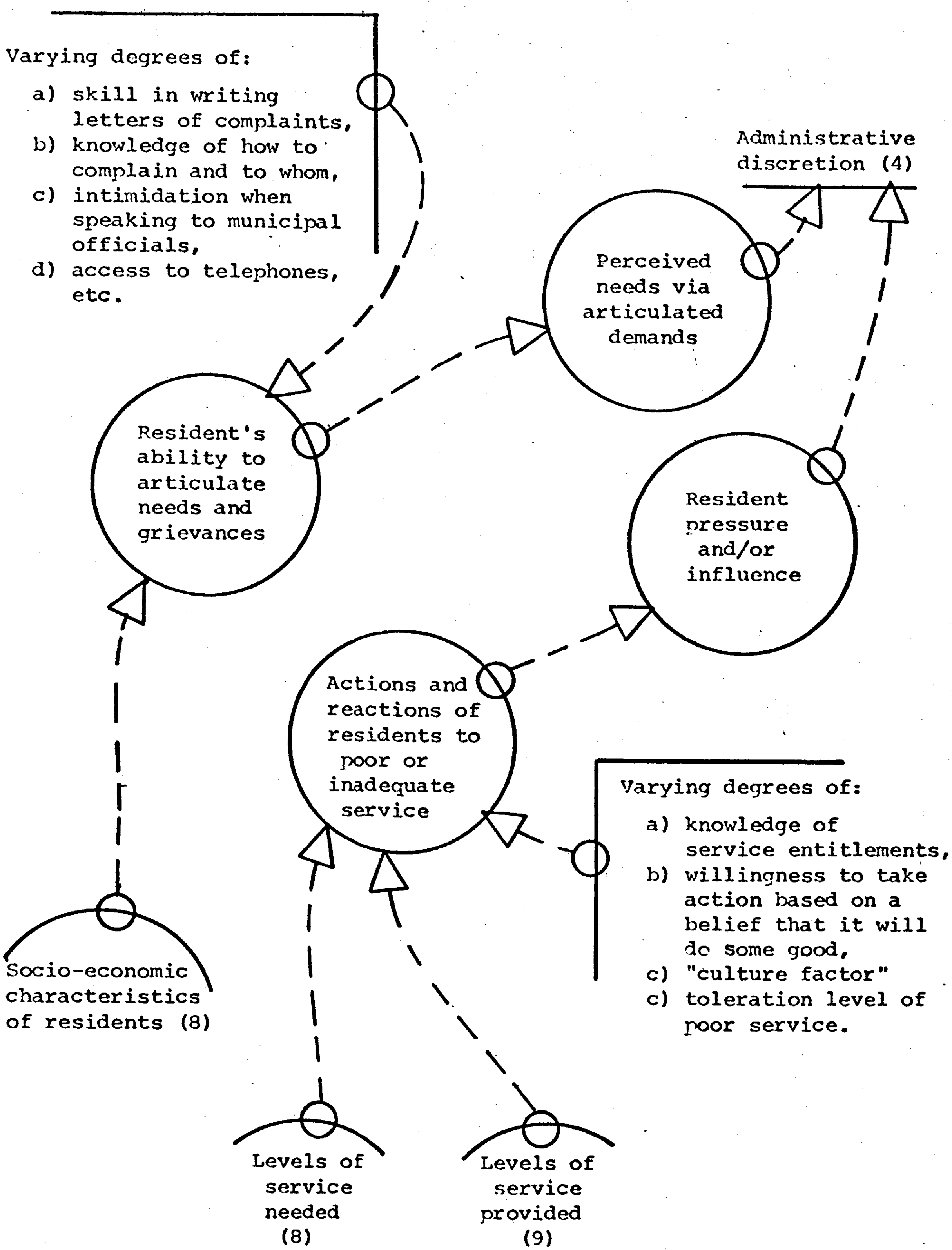


Figure 7: Secondary Factors Influencing Administrative Discretion

a councilman does indeed perceive that higher service levels in a neighborhood may be counter-productive. If service levels were markedly improved and if a low income area were suddenly showered with amenities, higher environmental quality may initiate intra-city migration into this neighborhood. The more affluent who had previously been repelled, may now be attracted. Their immigration might precipitate land speculation, increase property valuations, escalate tax payments and rent levels and drive out the low income residents. Not only is this forced outmigration injurious to the poor, but also to the political base of a politician whose ideologies may be quite different from that of the changing neighborhood. Thus, it is an odd twist of fate that says depressed service levels may be the price for neighborhood stability.

It is noted, however, that environmental quality is but one of the many factors contributing to the attractiveness of an area for intra-city migration. The quality of primary and secondary education, housing stock and others are also important. It does seem fair to say, however, that some tradeoffs must be made if one wishes to preserve low-income neighborhood stability.

These points are again modelled conceptually in Figures 8 and 9. Also shown in these figures is the phenomenum documented by Benson and Lund (see Appendix A) that the needs and preferences of residents are a function of their sociocultural and economic condition. Furthermore, the concept developed in Chapter II, that the level of service actually

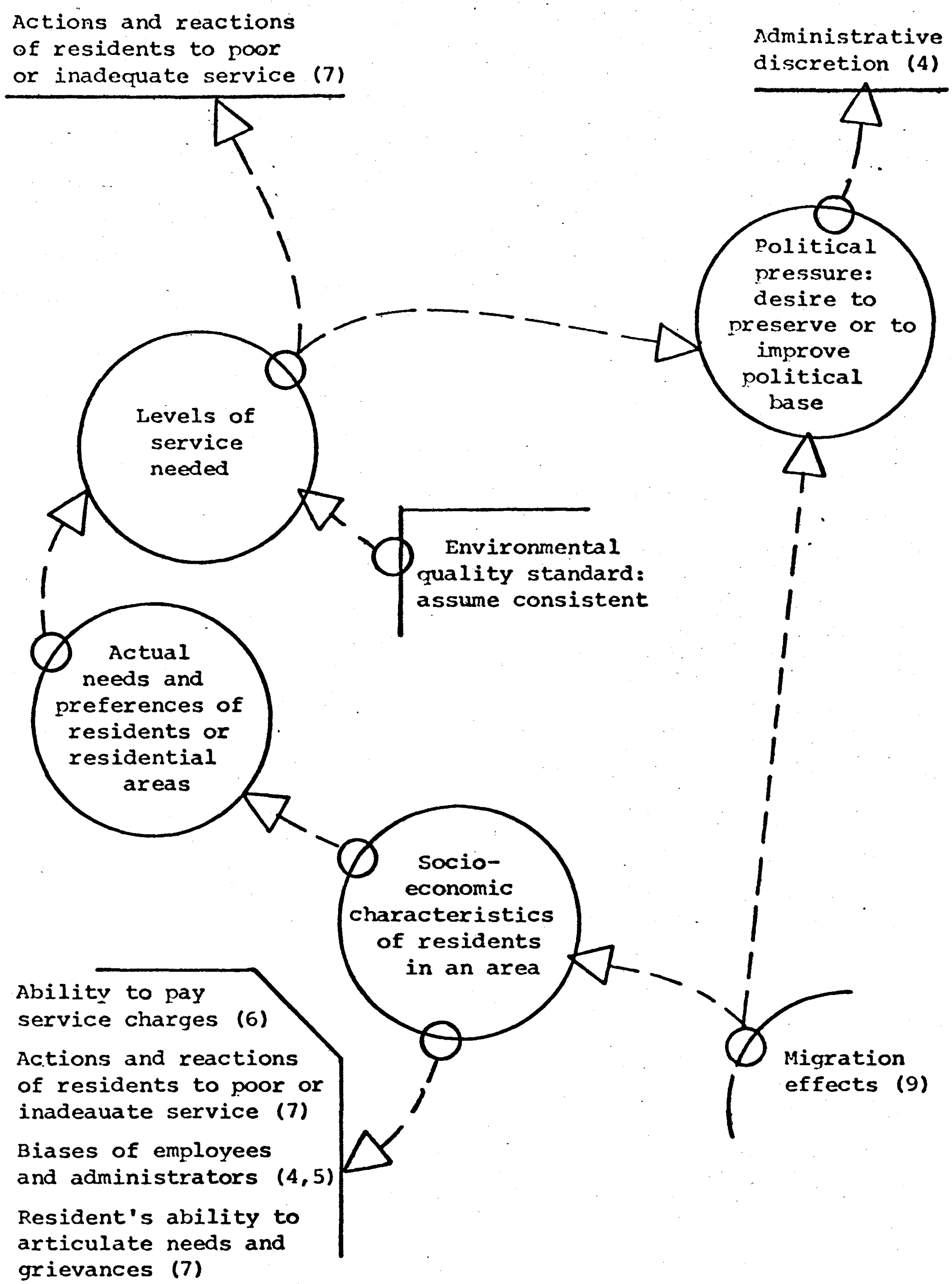


Figure 8: More Factors

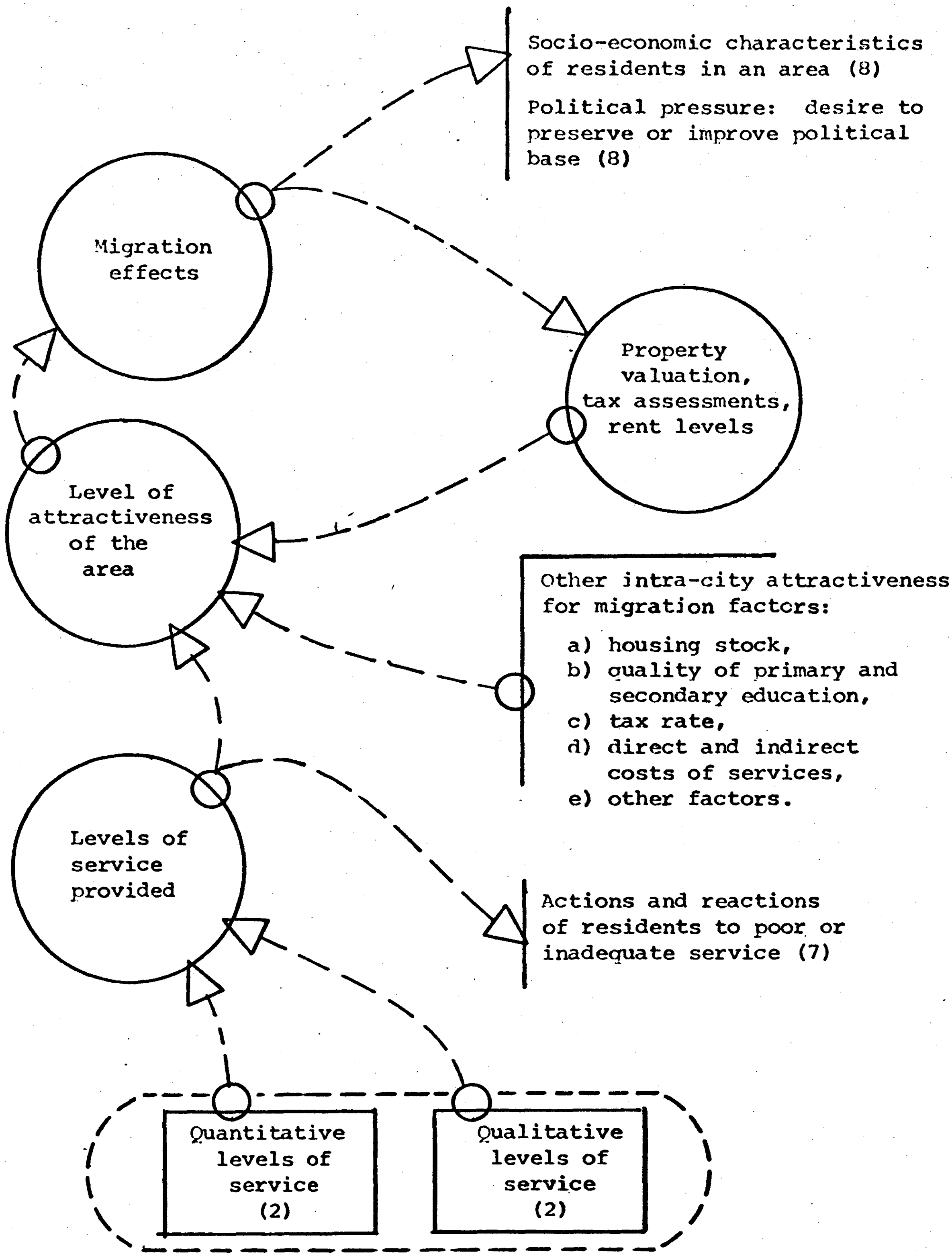


Figure 9: Level of Service and Migration Effects

provided is a function of both quantitative and qualitative levels, is shown in Figure 9.

In review, all of the factors mentioned above and in the previous sections tend to work against the lower classes in society. Poverty dictates that they shall be able to afford only very necessary services which are rendered for a fee. Poverty dictates that the poor may, indeed, be destined indefinitely to poor service as the price for low property valuations, low taxes and rent levels. Intra-city migration effects dictate that the overall attractiveness of a low-income area may be required to maintain a fixed <u>relative</u> position with respect to other areas, and that the only hope for better services lies in the improvement of the attractiveness of <u>all</u> areas, or in the sacrifice of public education, housing quality and other things. Powerlessness allows administrative discretion, influenced by many factors (Figure 4) and the biases of both employees and administrators to operate negatively in the distributive process and disparities result. Although the disadvantaged in society may indeed be described as poor, it is felt that a distinction should be made between poverty and powerlessness. The example of the better-serviced East Cambridge area illustrates that some may be poor (1960 Census data shows that incomes in this area ranged from $3,744 to $5,722) but not powerless.

Thus, as a general conclusion, the distributive process, as conceptualized in this study, excludes both the powerless and the poor from an equitable distribution of municipal services.

IV. STRATEGIES AND IMPLICATIONS

As one reflects upon the model of the distributive process, two sentiments emerge regarding relief strategies. One is a feeling that there is much which can be done to help the disadvantaged obtain fair treatment in the distribution of municipal services. But another is a feeling of caution and confusion about which strategies will in fact do more good than harm in the long run.

Although the reasons why disparities exist are fairly clear at this point, the long range effects of certain relief strategies are confusing at best. The model in Chapter III indicated, for example, that if some strategies were successful in achieving their objectives, the underlying forces which had caused the disparities in the first place might simply manifest themselves in different and possibly worse ways. But even if they did not, and these strategies were successful in equalizing environmental quality, the model again indicated that this success might endanger neighborhood stability and might force the poor to relocate outside the area of improvement.

Because of the confusing nature of these interactions and implications the author invested some effort in constructing a computer model of the distributive process in the hope of better understanding the long-range effects of different combinations of strategies. The model, as conceptualized in Chapter III, was programmed in DYNAMO II for the IBM 360/75 and a listing appears in Appendix B. For simplicity, it considered only one service, refuse collection, and two residential areas, a low-income area and a middle-upper-income area.

Referring occasionally to the conclusions of this model, the following discussion focusses upon several broad categories of strategies, considers specific strategies and their limitations and surmizes upon the implications of their successes. At this point, however, the ultimate goal of these strategies needs redefining. Originally, the goal was to achieve "equity in both the quantitative and qualitative distributions of municipal services." After much reflection and after a considerable number of computer runs it slowly became evident that this goal is an unreal one, that it is practically impossible to achieve environmental equality among socioculturally and economically different residential areas. However, it is possible to improve environmental quality in the disadvantaged areas; but this does not necessarily imply that disparities shall diminish as a result.

Towards this new goal several general categories of strategies are envisioned which aim at empowering the powerless, preventing service charging, improving service quality and raising service levels in all areas of a municipality.

The distributive process can be and is responsive to power. Although power can take many forms, the most apparent is political power --the incorporation of the alienated in society into the political processes. Its effectiveness is well documented by history and in current events. The Irish and Italian immigrants, for example, achieved significant gains through these means in the past, and more recently, the Negro poor in the south and in several major cities are beginning to assimilate some of the benefits of political incorporation. In this study, the poor, ethnically Italian but well-serviced East Cambridge area is yet another example of the benefits of political representation.

But this form of power is slow to achieve, and there are other forms which are more readily available to the residents themselves. Loosely categorized under the term "citizen involvement," several low profile strategies appear to be effective in obtaining some degree of better service. In Cambridge, for example, an individual resident, Nancy Bellows, successfully worked to have regular and thorough street cleaning on her street, even though DPW is notoriously lax in providing this service. The amount of effort required, however, was considerable, and it is admitted that she is well-educated and articulate. Nevertheless, the example points the way for advocates and social workers and others who might want to aid the disadvantaged. Another strategy could focus on the "complaint power" factor observed in the research, and might organize letter writing campaigns or might obtain signatures on petitions of complaint. Copies of these, in turn, could be sent to supervisors, administrators and high level officials. More formally, residents might do well to organize themselves into neighborhood associations. The case of the Beacon Hill Neighborhood Association clearly indicates the potential effectiveness of such an organization once it has been established. As indicated previously, however, these forms of citizen involvement are delicate, and for many reasons often do not appeal to the unsophisticated and disadvantaged.

Furthermore, if the reasons for poor service are more deeply rooted, such efforts on the part of residents will most likely fail to achieve any meaningful improvement. As such, grievances can accumulate, and the underlying tensions of the powerless may be released, as the Civil Disorders Report has recorded, in an extra-legal manner. After the disorders of Roxbury in the summer of 1967, Gordan notes[50] "a remarkable change had taken place" in the levels of service provided to this area. Garbage piles had been removed from vacant lots and the district's general condition was greatly improved.

But it is unfortunate, indeed, that the poor must resort to violence to obtain minimally adequate service. Furthermore, the long range effects of a riot upon service levels are debatable. When modelled in the computer simulation, a riot produced peak pressure on administrators, and they responded by drawing off resources previously allocated to other areas. But pressure in these areas began to rise as a result, and at the same time pressure in the riot area began to subside. After several months the service levels in both areas had returned to their original states.

In some special cases where the distribution of municipal services is so lopsided that discrimination is apparent, the disadvantaged may invoke the power of the law.

The central question in legal cases involving disparities in the distribution of municipal services provided free-of-charge is whether or not the courts should intervene in the exercising of administrative discretion. There are two arguments favoring the preservation of the discretion of municipal officials in controlling the distribution of services. The first is that the exercise of discretion is a necessary aspect of the allocation of scarce resources. Since available funds are generally insufficient to satisfy more than a fraction of all municipal needs, someone must decide which needs will be dealt with immediately and which ones will be postponed indefinitely. Such decisions should be made by elected or properly appointed officials who are accountable to the people affected. Judges are ill-suited for involvement in the intricacies of such fiscal policy-making. The second argument focusses on the premise that the successful administration of any service, whether it be providing police protection, managing refuse collection operations, or overseeing the repair and maintenance of the sewer system, requires the freedom to innovate and react to unanticipated situations. The intervention of the courts into official decision-making may inhibit creative administration and introduce rigidity into the treatment of social problems, by prohibiting more flexible and discretionary approaches.

Admittedly, some discretion is needed. But unchecked discretion is often abused, and the misery, despair, and alienation of many of the powerless and the poor in society dictate that control in one form or another is also necessary. The equal protection clause in the Fourteenth Amendment provides one entry for this control.

It has been argued successfully[51] that if one neighborhood receives inadequate municipal services while another neighborhood receives excellent municipal services, and if there is no rational basis for the difference, then the residents of the first neighborhood are being denied equal protection under the laws. The equal protection clause does not require a municipality to provide any service at all, but if a municipality does undertake to provide a service, then it must do so on a nondiscriminatory basis. The question remains, though, of defining "equal treatment." In the case of Hawkins v. Shaw, it was clear that there was unequal treatment. The services in question were local improvements which are easily quantifiable, and one area received nearly all these services while the other received none. In cases where the issues involve quality rather than quantity and concern services which are rendered according to needs, however, the question of equal treatment will be a difficult one to answer.

The court ruled in this case that the town failed to provide any compelling reason which could justify the vast disparities in the distribution of municipal services. Pending appeal to the U. S. Supreme Court, the town is ordered to provide street paving, street lighting, curbing, sewerage, water mains, fire hydrants, traffic lights and sidewalks in the black area of Shaw where almost none of these services now exist. Presumably, the costs of such an undertaking will be relatively enormous for a small town.

Since the services in question are indeed amenable to service charging, one might speculate that the town could simply shift its service policies and circumvent the court order. By affixing service charges to such local improvements, the town might successfully deny the poor these services economically, or might argue that it is too risky to finance such services in their area. It is noted that when litigation was simulated in the computer model, it had negligible affects upon service levels in cases where disparities were large but not as clearly quantifiable as those above. In refuse collection, for example, a large portion of disparity is due to qualitative differences and not to quantitative differences. Furthermore, in the ambiguous cases the courts have ruled in favor of the preservation of administrative discretion.[52]

For some services, the enactment of service charging would be ideal if the costs of the services were subsidized on the part of the poor. Today there is national and state subsidization of the poor for the costs of food, clothing, shelter and other needs; is it not reasonable to include among these a few of the basic municipal services as well? If one wishes to equalize society as well as environmental quality, then service charging would be ideal if coupled with income transfers to the poor, for this scheme would help to achieve more redistributive effects.

However, since this subsidization does not seem likely in the near future, some strategies should focus on the prevention of policy shifts toward service charging. As it was pointed out in Chapter III, the consequences of such a shift would be injurious to the poor; they would have to pay out a larger percentage of their incomes for the most necessary of services which they had received free before, and would be denied economically others which they could not afford but could live without. The purpose of imposing service charges, however, is not to exclude anyone, but simply to finance the costs of the services and to relieve overall fiscal pressure.

Thus, one general category of strategies could aim at relieving fiscal pressure. This proposal invites numerous suggestions, but one that stands out in particular is national legislation to alleviate the financial crises of urban areas--a concept currently embodied in "revenue sharing." Other strategies, however, focus upon reducing service costs and increasing efficiency.

Evidence indicates that municipal agencies, as a rule, are poorly managed. Certainly this is so in Cambridge. There are innumerable ways in which research and innovation can be applied to municipal service systems. As one example, refuse collection vehicles in Cambridge use no routing plans; they frequently miss streets altogether, and routes in several districts are not contiguous. The result of this is increased overtime to cover the missed streets, the hiring of additional private contractors and the assignment of "routing" cars to lead the collection vehicles through the maze of non-contiguous routes--all contributing to monetary wastefulness. Furthermore, if routes were instituted for street cleaning, street inspection and other services, perhaps services might be distributed more equitably. Thus, solutions to the routing problem combined with numerous other innovations could all contribute to the reduction of service costs, improvement of service efficiency and distribution, and to the increase of service levels in all neighborhoods. As an example of the applicability of modern mathematical and heuristic techniques to public sector problems, the author's own work on the refuse collection vehicle routing problem above is included in Appendix C.

Although preventing service charging may be one special consequence of fiscal relief and service efficiency, the more common benefits are simply that more resources are available for allocation. In the computer simulation of the distributive process, two specific strategies when implemented together did more for the disadvantaged than all others. These were: an increase in resources, reflecting both increased service efficiency and an increase in service budgets, and the imposition of better management in municipal agencies. More resources allowed more services to be distributed to all areas and better management induced higher quality levels in the low income areas, although it did not affect significantly the quantitative proportions between the two areas. Although one must not rely too heavily on this simulation, the implications of its conclusions seem reasonable.

It is difficult if not impossible to achieve some measure of environmental equality among residential areas with vastly different sociocultural and economic characteristics. But it is possible to achieve some measure of service adequacy for the disadvantaged. Admittedly, however, to do this seems to require giving other areas much more than simply adequate service, and disparities in the distribution of municipal services seem destined to exist indefinitely.

APPENDICES

APPENDIX A: PUBLIC SERVICES AND SOCIO-ECONOMIC PARTICIPATION RATES

Regarding the question of what is an equitable distribution of municipal services, it may be appropriate to say that for some services equal (pro rata) amounts would be equitable; but for others this measure is clearly inappropriate. Some residential areas have far greater needs for health and sanitation services, for remedial and police services, than do others. It has been claimed throughout this thesis that the needs and preferences of different residential areas, for certain kinds of services may vary, and that they reflect the different sociocultural and economic conditions of their respective areas. As evidence in support of this, the following study is briefly reviewed.

Benson and Lund,[53] of the Institute of Governmental Studies at the University of California, Berkeley, conducted a one-year study of the neighborhood distribution of local public services. One objective of the study was to examine the hypothesis that upper and middle income households, which are more mobile than lower income households, will remain in a community only as long as they perceive that a large portion of their tax payments are allocated to the support of services which they use rather than to the support of remedial and income transfer programs. Thus, a major assumption at the outset of the study was that different groups of residents used and consumed different types of services in varying rates and that these rates could be systematically related to observable socio-economic characteristics such as income, education and occupation of the heads of households.

They chose three distinct neighborhoods in Berkeley which were, generally speaking, internally similar with respect to income, education and occupational level of the head of the household as shown in Table 5. Area A was characterized by "low" values in socio-economic indicators, Area C by "high" values, and Area B by values somewhere near the middle. The public services which they examined were of six categories: health, police, inspection, libraries, recreation and education. Although these services are much broader in nature than municipal services, police, environmental sanitation, inspection and recreational services were all included in the study.

The results of their research suggest that the demand for certain kinds of services varies significantly among different kinds of neighborhoods. Using the notation shown in Table 6 , one can observe in Table 7 a distinct correlation between participation and socio-economic characteristics.

Subsequently, Benson and Lund categorized services into two sets in the conclusions of their report, "Neighborhood Distribution of Local Public Services." Services were categorized according to use characteristics such that in one were "poverty-related services" and in the other were "developmental services." Poverty-related services consist of remedial services, services which relate to the incidence of physical handicaps or disease in poor households, and services which reflect the socially disruptive activities that concentrations of poverty appear to breed. Developmental services include educational

Table 5
U.S. Census of Population (1960) Data
for Three Berkeley Neighborhoods

Area		Population 1960	Median Family Income 1959	Median School Years 1960	Ratio of Prof/Skilled Worker to Semi/Unskilled 1960
A					
Census Tract	2A	2,997	$5,188	10.7	2:3
	2B	4,997	4,750	10.4	1:2
	2C	3,968	5,128	12.1	8:9
	2D	3,130	6,307	11.0	1:1
Total		15,072			
B					
Census Tract	4C	6,027	6,520	12.7	4:1
	4D	3,535	6,420	12.0	2:1
	4E	5,264	6,486	12.4	3:2
Total		14,826			
C					
Census Tract	6B	3,850	10,926	16+	16:1
	6C	2,159	11,902	16+	15:1
	6D	4,143	12,283	16+	13:1
	6E	4,532	8,590	13.1	7:1
Total		14,684			

Table 6
Categories of Participation
(Each neighborhood = 1-% of Berkeley population)

% of the Neighborhood's Share of Services	Involvement Rating	Symbol Used in Table
Less than 5%	Very low	VL
5 - 9.9	Low	L
10 - 19.9	Typical	T
20 - 24.9	High	H
25 and over	Very high	VH

Table 7
Partial Summary:
Relative Degree of Participation of Neighborhoods in Local Public Services

Service	Neighborhood		
	A	B	C
<u>Health</u>			
Nursing:			
Chronic Disease	VH	L	VL
Acute Communicable Disease	VH	L	T
Environmental Sanitation	VH	T	L
Tuberculosis:			
Clinic	VH	T	VL
Nursing Visits	VH	T	L
Venereal Disease:			
Nursing Visits	VH	VL	T
Other	VH	L	VL
<u>Police</u>			
Detective	H	T	L
Juvenile	VH	T	L
Ambulance	H	T	L
Special Detail	VH	L	L
Beat Patrol	H	L	T
<u>Inspection</u>			
Zoning Complaints	L	VL	VH
Other Specific Calls	VH	VH	VL
Block-by-Block Survey	VH	VL	VL
<u>Libraries</u>			
Main Circulation	VL	T	T
Branch Circulation	L	T	VH
<u>Recreation</u>			
Recreation Centers	VH	L	L
Workreation	T	T	H
Vacation Camps	VL	L	VH
<u>Education</u>			
Senior High School:			
Regular	T	T	T
Special Programs	H	T	VL

services, libraries and recreational activities. Clearly, different residents have different needs and preferences for certain kinds of services, and these needs and preferences are correlated to socio-economic characteristics. It must be added, however, that these conclusions are not to imply that different classes in society have different needs and preferences for all services. Preferences for environmental amenities, for example, may be identical among different classes even though the upper classes may receive more in the processes of distribution.

APPENDIX B: DYNAMO MODEL OF THE DISTRIBUTIVE PROCESS

Following this page is a listing of a computer model of the distributive process for municipal services rendered free-of-charge as it was conceptualized in Chapter III. The model was programmed in DYNAMO II [54] for the IBM 360/75 computer. The purpose was primarily to lend understanding to the interactions of the different variables and forces acting within the process and to provide insights into the effects and implications of specific relief strategies. For simplicity, the model simulates only one service, refuse collection, and considers only two, but polarized, areas in a municipality.

A thorough description of the model is felt to be unnecessary here and would be rather tedious. Generally speaking, its construction reflects the explicit schematic diagrams in Chapter III, but if one wishes to study it more carefully or use it as an example for other simulations, a documented listing is provided.

```
*  MUNICIPAL SERVICES ALLOCATION MODEL
NOTE
NOTE   ---THE FOLLOWING MODEL IS FOR REFUSE COLLECTION SERVICES
NOTE
NOTE
NOTE I. COMMUNITY GENERATOR:
NOTE      SOCIO-ECONOMIC CHARACTERISTICS OF TWO AREAS WITHIN A
NOTE      MUNICIPAL JURISDICTION ARE GENERATED EXOGENOUSLY.
NOTE      THE TWO AREAS START AS IDENTICAL, AREA1 THEN DECAYS AS
NOTE      AREA2 IMPROVES.
NOTE
A      S1.K=TABLE(S1T,TIME.K,0,50,10)          SOC/EC INDICATOR
T      S1T=5/4/3/2/1/1
A      S2.K=TABLE(S2T,TIME.K,0,50,10)          SOC/EC INDICATOR
T      S2T=5/6/7/8/9/9
A      POP1.K=TABLE(P1T,TIME.K,0,50,50)        POPULATION
T      P1T=40000/40000
A      POP2.K=TABLE(P2T,TIME.K,0,50,50)        POPULATION
T      P2T=40000/40000
A      PD1.K=TABLE(PDT,S1.K,0,10,10)           POP DENSITY (PEOPLE/SQ MI)
A      PD2.K=TABLE(PDT,S2.K,0,10,10)           POP DENSITY (PEOPLE/SQ MI)
T      PDT=25000/5000                          POP DENS TABLE
NOTE
NOTE
NOTE II. MONETARY CONSTRAINTS UPON THE ALLOCATION OF SERVICE:
NOTE      BIWEEKLY BUDGET IS COMPUTED OVER  ONE QUARTER YEAR
NOTE      TOTAL SERVICE UNITS COMPUTED FROM BUDGET
A      BB.K=SMOOTH(DBB.K,BDEL)                 BIWEEKLY BUDGET
A      DBB.K=(1.0-CF.K)(CPSUC)(SUN1.K+SUN2.K)  DESIRED BUDGET
A      CF.K=C1*CLIP(0,1,SWT3,TIME.K)           COST FACTOR
C      SWT3=20
L      TSU.K=TSU.J+DT*(TSUPP.JK-SUAPP1.JK-SUAPP2.JK)
R      TSUPP.KL=BB.K/CPSUC                     TSU PER PERIOD
A      TSNR.K=TSU.K/(SUN1.K+SUN2.K)            TOT SERV TO NEEDS RATIO
NOTE
NOTE
```

```
NOTE III. ALLOCATIONAL SUBMODEL FOR AREA1:
NOTE  A. ALLOCATION OF SERVICE UNITS (SU)---
L     SUA1.K=SUA1.J+DT*(SUAPP1.JK-SUCPP1.JK)   SU ALLOC PER PERIOD
R     SUCPP1.KL=SUA1.K                        SU CONSUMED PP
R     SUAPP1.KL=SUAEC1.K+SUAAP1.K             SU ALLOC PER PERIOD
A     SUAEC1.K=(SUD1.K)(SMOOTH(EC.K,ECDEL)) SU ALLOC BY EXOG CONSTRAINTS
A     EC.K=ECV*CLIP(0,1,20,TIME.K)            EXOGENOUS CONSTRAINTS ON ALLOC
A     SUD1.K=TSU.K*PN1.K                      SU DESIRED WITHIN FEASIBILITY
A     PN1.K=SUN1.K/(SUN1.K+SUN2.K)            DESIRED FRACTIONAL SPLIT
A     SUN1.K=(RG1.K/CAPSU)*(PDF1.K)           SERVICE UNITS NEEDED
A     RG1.K=POP1.K*RGPC1.K/26                 REFUSE GENERATED PER PERIOD
A     RGPC1.K=TABLE(RGPCT,S1.K,0,10,5)        REF GEN PER CAPITA (CU YD/YR)
T     RGPCT=0.90/1.40/1.80                    RGPC TABLE (CUBIC YDS PER YR)
A     PDF1.K=TABLE(PDFT,PD1.K,5000,25000,5000)  POP DENSITY FACTOR
T     PDFT=1.0/1.075/1.15/1.4/1.6             POP DENS FACTOR TABLE
A     SUADR1.K=SUA1.K/SUD1.K                  SU ALLOC TO DESIRED RATIO
A     SANR1.K=SUA1.K/SUN1.K                   SU ALLOC TO NEEDED RATIO
A     SUAAP1.K=SUU.K*NRAP1.K                  SU ALLOC BY ADMIN PROCESS
A     SUU.K=TSU.K-SUAEC1.K-SUAEC2.K           SU UNALLOC
A     NRAP1.K=FAP1.K/(FAP1.K+FAP2.K)          NORMALIZED RATIO OF FAP'S
A     FAP1.K=AD1.K*PI1.K                      FACTORS IN THE ADMIN PROCESS
NOTE
NOTE
NOTE  B. ALLOCATION OF QUALITY OF SERVICE VIA ADMIN CONTROL---
L     AQSU1.K=AQSU1.J+DT*(QS1.JK-QC1.JK)      AVG QUAL LEVEL OF SU IN AREA
R     QS1.KL=TABHL(AQSUT,QF1.K,0,2,1)         QUAL SUPPLIED (0-100%)
T     AQSUT=.80/.95/1.00
A     QF1.K=EB1.K+AC1.K                       QUAL FACTOR
A     EB1.K=TABLE(EBT,S1.K,0,10,5)            EMPLOYEE BIASES
T     EBT=0.5/1.0/1.2                         EMPLOYEE BIAS TABLE
A     AC1.K=TABHL(ACT,AD1.K,0,2,1)            ADMIN CONTROL
T     ACT=0/0/1                               ADMIN CONTROL TABLE
R     QC1.KL=AQSU1.K                          QUAL CONSUMED (= QUAL SUP)
A     LOSP1.K=SUA1.K*AQSU1.K                  LEVEL OF SERVICE PROVIDED
A     LOSN1.K=SUN1.K*1.00                     LEVEL OF SERVICE NEEDED
A     LOSR1.K=LOSP1.K/LOSN1.K                 LEVEL OF SERVICE RATIO
NOTE
```

```
NOTE
NOTE   C. FACTORS INFLUENCING THE ALLOCATIONAL PROCESS---
NOTE   --1. ADMINISTRATIVE DISCRETION
A      AD1.K=(EQS1.K+RDPM1.K)/2                  ADMINISTRATIVE DISCRETION
NOTE   ---(A) ENVIRONMENTAL QUALITY STANDARD
A      EQS1.K=TABHL(EQST,AB1.K,-1,1,1)           ENV QUAL STD (NOT EXPLICIT)
T      EQST=0/1/2                                EQS TABLE
A      AB1.K=BI.K*TABHL(MABT,S1.K,0,10,5)        ADMINISTRATOR BIAS
A      BI.K=BA1+BA2*CLIP(0,1,20,TIME.K)          BIAS AMPLIFIER
T      MABT=-.3/0/.2                             MODERATE ADMIN BIAS TABLE
NOTE   ---(B) RESIDENT DEMANDS/PRESSURE MULTIPLIER
A      RDPM1.K=TABHL(RDPMT,RRDP1.K,0,2,.25) RES DEM/PRESSURE MULT
T      RDPMT=0.0/.5/.7/.85/1.0/1.15/1.30/2.00/3.00
A      RRDP1.K=(RDP1.K*2.0)/(RDP1.K+RDP2.K) RELATIVE RDP'S
NOTE   RDP1.K=RES DEMANDS/PRESSURE
A      RDP1.K=(SWT1.K+(1-SWT1.K)(PNM1.K)(RDF1.K))+SMOOTH(RPF1.K,PFDEL)
N      RPF1=0                                    RES PRESSURE FACTOR (RIOT)
A      SWT1.K=CLIP(0,1,RDF1.K,1.01)
NOTE   RDF1.K=RESIDENTS DEMANDS FACTOR
A      RDF1.K=TABHL(RIMT,S1.K,0,10,5)*TABHL(RGMT,GV1.K,0,1,.2)
T      RIMT=.7/1.0/2.0  RES INTOLERANCE (OF POOR SERVIVCE) MULT TABLE
T      RGMT=1.0/1.3/1.5/1.8/2.8/4.0  RES GREIVANCES MULT TABLE
A      GV1.K=(LOSN1.K-LOSP1.K)/LOSN1.K           GREIVANCES
NOTE   RPF1.K=RES PRESSURE FACTOR
A      RPF1.K=CLIP(0,1,NOISE(),PF1.K)*TABHL(RGMT,GV1.K,0,1,.2)(RIF)
A      PF1.K=TABHL(PFT,LOSR1.K,0,1,.1)           PRESSURE FACTOR
T      PFT=.5/.45/.4/.35/.30/0.0/-.25/-.40/-.48/-.5/-.5
A      PNM1.K=((RUMC.K)+(1-RUMC.K)(RAAD1.K)) PERCEIVED NEEDS MULT
A      RUMC.K=TABLE(RUMCT,GTP.K,0,10,2.5)        RELIANCE UPON MANAGEMENT CONTROL
T      RUMCT=0/.15/.30/.75/1.0
A      GTP.K=5+(GTYPE)*CLIP(0,1,20,TIME.K)       TYPE OF GOV'T (EFFICIENCY)
C      GTYPE=0
A      RAAD1.K=TABLE(RAADT,S1.K,0,10,5)          RES ABILITY TO ARTICULATE DESIRES
T      RAADT=.4/1.0/1.2                          RAAD TABLE
NOTE   --2. POLITICAL INFLUENCE UPON THE ALLOC PROCESS
NOTE   PI1.K IS NOT MODELLED
```

```
A       PI1.K=1.0
NOTE
NOTE
NOTE IV. ALLOCATIONAL SUBMODEL FOR AREA2:
NOTE    A. ALLOCATION OF SERVICE UNITS (SU)---
L       SUA2.K=SUA2.J+DT*(SUAPP2.JK-SUCPP2.JK)    SU ALLOC PER PERIOD
R       SUCPP2.KL=SUA2.K                          SU CONSUMED PP
R       SUAPP2.KL=SUAEC2.K+SUAAP2.K               SU ALLOC PER PERIOD
A       SUAEC2.K=(SUD2.K)(SMOOTH(EC.K,ECDEL))     SU ALLOC BY EXOG CONSTRAINTS
A       SUD2.K=TSU.K*PN2.K                        SU DESIRED WITHIN FEASIBILITY
A       PN2.K=SUN2.K/(SUN1.K+SUN2.K)              DESIRED FRACTIONAL SPLIT
A       SUN2.K=(RG2.K/CAPSU)*(PDF2.K)             SERVICE UNITS NEEDED
A       RG2.K=POP2.K*RGPC2.K/26                   REFUSE GENERATED PER PERIOD
A       RGPC2.K=TABLE(RGPCT,S2.K,0,10,5)          REF GEN PER CAPITA (CU YD/YR)
A       PDF2.K=TABLE(PDFT,PD2.K,5000,25000,5000)  POP DENSITY FACTOR
A       SUADR2.K=SUA2.K/SUD2.K                    SU ALLOC TO DESIRED RATIO
A       SANR2.K=SUA2.K/SUN2.K                     SU ALLOC TO NEEDED RATIO
A       SUAAP2.K=SUU.K*NRAP2.K                    SU ALLOC BY ADMIN PROCESS
A       NRAP2.K=FAP2.K/(FAP1.K+FAP2.K)            NORMALIZED RATIO OF FAP'S
A       FAP2.K=AD2.K*PI2.K                        FACTORS IN THE ADMIN PROCESS
NOTE
NOTE
NOTE    B. ALLOCATION OF QUALITY OF SERVICE VIA ADMIN CONTROL---
L       AQSU2.K=AQSU2.J+DT*(QS2.JK-QC2.JK)        AVG QUAL LEVEL OF SU IN AREA
R       QS2.KL=TABHL(AQSUT,QF2.K,0,2,1)           QUAL SUPPLIED (0-100%)
A       QF2.K=EB2.K+AC2.K                         QUAL FACTOR
A       EB2.K=TABLE(EBT,S2.K,0,10,5)              EMPLOYEE BIASES
A       AC2.K=TABHL(ACT,AD2.K,0,2,1)              ADMIN CONTROL
R       QC2.KL=AQSU2.K                            QUAL CONSUMED (= QUAL SUP)
A       LOSP2.K=SUA2.K*AQSU2.K                    LEVEL OF SERVICE PROVIDED
A       LOSN2.K=SUN2.K*1.00                       LEVEL OF SERVICE NEEDED
A       LOSR2.K=LOSP2.K/LOSN2.K                   LEVEL OF SERVICE RATIO
NOTE
NOTE
```

```
NOTE   C. FACTORS INFLUENCING THE ALLOCATIONAL PROCESS---
NOTE   --1. ADMINISTRATIVE DISCRETION
A      AD2.K=(EQS2.K+RDPM2.K)/2                   ADMINISTRATIVE DISCRETION
NOTE   ---(A) ENVIRONMENTAL QUALITY STANDARD
A      EQS2.K=TABHL(EQST,AB2.K,-1,1,1)            ENV QUAL STD (NOT EXPLICIT)
A      AB2.K=BI.K*TABHL(MABT,S2.K,0,10,5)         ADMINISTRATOR BIAS
NOTE   ---(B) RESIDENT DEMANDS/PRESSURE MULTIPLIER
A      RDPM2.K=TABHL(RDPMT,RRDP2.K,0,2,.25)       RES DEM/PRESSURE MULT
A      RRDP2.K=(RDP2.K*2.0)/(RDP1.K+RDP2.K)       RELATIVE RDP'S
NOTE   RDP2.K=RES DEMANDS/PRESSURE
A      RDP2.K=(SWT2.K+(1-SWT2.K)(PNM2.K)(RDF2.K))+SMOOTH(RPF2.K,PFDEL)
N      RPF2=0                                     RES PRESSURE FACTOR (RIOT)
A      SWT2.K=CLIP(0,1,RDF2.K,1.01)
NOTE   RDF2.K=RESIDENTS DEMANDS FACTOR
A      RDF2.K=TABHL(RIMT,S2.K,0,10,5)*TABHL(RGMT,GV2.K,0,1,.2)
A      GV2.K=(LOSN2.K-LOSP2.K)/LOSN2.K            GREIVANCES
NOTE   RPF2.K=RES PRESSURE FACTOR
A      RPF2.K=CLIP(0,1,NOISE(),PF2.K)*TABHL(RGMT,GV2.K,0,1,.2)(RIF)
A      PF2.K=TABHL(PFT,LOSR2.K,0,1,.1)            PRESSURE FACTOR
A      PNM2.K=((RUMC.K)+(1-RUMC.K)(RAAD2.K))      PERCEIVED NEEDS MULT
A      RAAD2.K=TABLE(RAADT,S2.K,0,10,5)           RES ABILITY TO ARTICULATE DESIRES
NOTE   --2. POLITICAL INFLUENCE UPON THE ALLOC PROCESS
NOTE   PI2.K IS NOT MODELLED
A      PI2.K=1.0
NOTE
NOTE   INITIAL VALUE CARDS
N      DBB=14682                                  (DOLLARS)
N      TSU=826                                    TOTAL SERVICE UNITS
N      SUA1=413
N      SUA2=413
N      EC=0
N      AQSU1=.95
N      AQSU2=.95
NOTE
NOTE   CONSTANT DEFINITION CARDS
C      BDEL=16                                    BUDGET DELAY (PERIODS)
C      C%=0                                       % INCREASE/DECREASE
C      CPSUC=18                                   CPSU CONSTANT
```

```
C       ECV=0                                  EC VALUE (% OF SU ALLOC)
C       CAPSU=6                                CAPACITY PER SU (CU YDS)
C       ECDEL=10                               EC TIME DELAY (PERIODS)
C       BA1=1.0
C       BA2=0.0
C       RIF=1.0                                RIOT INTENSITY FACTOR (SENS'Y)
C       PFDEL=3                                PRESSURE FACTOR TIME DELAY
NOTE
NOTE    CONTROL CARDS
C       DT=1
C       LENGTH=50
A       PLTPER.K=CLIP(PLTMIN,PLTMAX,PLTCT,TIME.K)
C       PLTMIN=1
C       PLTMAX=1
C       PLTCT=500
A       PRTPER.K=CLIP(PRTMIN,PRTMAX,PRTCT,TIME.K)
C       PRTMIN=5
C       PRTMAX=10
C       PRTCT=30
PRINT 1)(0,0)SUA1,SUAAP1,SUAEC1,SUD1,SUN1
PRINT 2)(0,0)SUA2,SUAAP2,SUAEC2,SUD2,SUN2
PRINT 3)(0,0)RG1,LOSP1,LOSN1,TSU,BB
PRINT 4)(0,0)RG2,LOSP2,LOSN2,*,DBB
PRINT 5)(0,3)S1,PN1,RGPC1,PDF1,SUADR1,NRAP1
PRINT 6)(0,3)S2,PN2,RGPC2,PDF2,SUADR2,NRAP2
PRINT 7)(0,3)FAP1,QS1,QF1,EB1,AC1,LOSR1
PRINT 8)(0,3)FAP2,QS2,QF2,EB2,AC2,LOSR2
PRINT 9)(0,3)AD1,EQS1,RDPM1,AB1,RRDP1,RDP1
PRINT 10)(0,3)AD2,EQS2,RDPM2,AB2,RRDP2,RDP2
PRINT 11)(0,3)RDF1,PNM1,RAAD1,GV1,PF1,SANR1
PRINT 12)(0,3)RDF2,PNM2,RAAD2,GV2,PF2,SANR2
PRINT 13)(0,3)TSNR,AQSU1,AQSU2
PLOT    S1=1(0,20)/SUA1=S,SUN1=N(200,600)/AQSU1=Q(.7,1.1)/RPF1=C(0,10)/LOS
X       R1=L,EQS1=E,RDPM1=D,PNM1=P,AD1=A(.5,1.5)
PLOT    S2=2(0,20)/SUA2=S,SUN2=N(200,600)/AQSU2=Q(.7,1.1)/RPF2=C(0,10)/LOS
X       R2=L,EQS2=E,RDPM2=D,PNM2=P,AD2=A(.5,1.5)
RUN DISPLAY: TRANSITIONAL INTERACTIONS
TP      S1T=2.5/2.5/2.5/2.5/2.5/2.5
TP      S2T=7.5/7.5/7.5/7.5/7.5/7.5
```

```
RUN POLARIZED COMMUNITIES: EQUILIBRIUM
CP    BA2=1.0
CP    GTYPE=-2
CP    C1=.10
RUN SOUTHERN TOWN
RUN SOUTHERN TOWN EQUILIBRIUM
CP    BA2=0
CP    C1=-.10
CP    GTYPE=4
CP    ECV=.75
RUN GOOD GOVERNMENT
RUN GOOD GOVERNMENT EQUILIBRIUM
```

APPENDIX C: PUBLIC SECTOR VEHICLE ROUTING--OPTIMIZATION AND HEURISTIC TECHNIQUES

At several places in the text, the point has been made that fiscal pressure and the rising costs of municipal services are not the only important factors influencing the distribution of municipal services among all residents, but are also potentially injurious to the powerless and the poor. Rising costs may precipitate service cuts and these fall hardest upon those least able to resist them or may force municipal policies to shift toward greater use of service charging. As explained in several places, service charging can force the poor to pay even larger percentages of their incomes for basic needs, or may deny them economically services which they may now receive.

As fiscal pressure increases with rising costs, growing demands and lagging resources, many municipalities are somewhat belatedly beginning to invest in research and technological innovation as a means of increasing efficiency. Increased efficiency may result in higher quality of service, but more importantly may avoid, or at least forestall reductions in service levels. Presented below is one application of research and technological innovation to the problem of public sector vehicle routing.

ANALYSIS OF THE REFUSE COLLECTION PROBLEM

Although the problem of refuse disposal has been the focus of much attention in the light of recent environmental concern, a study by

Ludwig and Black[55] reveals that 85 percent of the solid waste system costs in this country is due to collection, while only 15 percent is due to disposal. Thus, in the short run at least, some of the financial pressure upon the solid waste system may be relieved by improving collection efficiency.

There are many facets of the collection system operations which lend themselves to analysis: manpower allocation, incentive systems, capital budgeting for equipment and others. Marks and Liebman[56] have noted, for example, that a significant inefficiency in current collection operations is the long trip to the dumping site which the garbage truck and its crew must make two or three times a day. They have suggested a scheme for setting up local transfer facilities where the collection vehicle transfers its load to a different vehicle which is more suited for making the longer runs, while allowing the garbage truck to make more use of its time collecting refuse rather than carrying it. The particular facet chosen for analysis here, however, is that of routing the vehicles along city streets. Stricker[57] analyzes part of the routing problem as follows:

> "As vehicles have become larger and more efficient, each one can service a greater area with no increase in the size of the crew. Due to the complexity of the [rerouting] problem, though, as collection fleets become mondernized, instead of completely restructuring routes . . . city administrators merely append bits and pieces of a phased out route to remaining routes. This often results in obvious inefficiencies such as routes which are no longer contiguous."

Furthermore, Stricker cites in his study of Cambridge, Massachusetts, increased overtime, the hiring of additional private contractors and the assignment of "routing" vehicles to lead the collection vehicles through the maze of non-contiguous routes as examples of monetary wastefulness directly resulting from inefficient routing.

There is, of course, a difference between the "best" route and the most efficient route. Objectives such as the equalization of work loads, promoting compatibility between truck capacity and estimated pickup loads, and the districting of routes in an optimal way with respect to long haul dump trips are perhaps more important considerations. Given the district boundaries, however, the routing problem then becomes one of how to travel every street while minimizing total distances travelled.

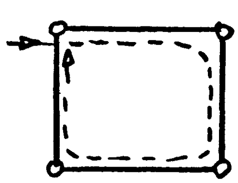
INTRODUCTION TO THE CHINESE POSTMAN PROBLEM

The problem of finding the shortest route through a street network such that every street is travelled at least once has interested man for centuries. This problem is basic not only to the operations of refuse collection, but also to other public sector operations such as street cleaning. The related problem, known in network theory as the Chinese Postman Problem[58], is to trace the shortest continuous path through a network such that every arc is covered at least once. Before continuing, the following simple definitions are presented to avoid confusion in terminology:

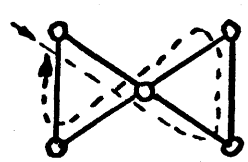
arc	a line joining two and only two nodes
node	a point of junction of two or more arcs
network	a set of nodes plus a set of arcs connecting them. Same as graph.

directed arc	an arc which may be traversed only in in a specific direction
undirected arc	an arc which may be traversed in either direction
directed network	a network composed only of directed arcs
undirected network	a network composed only of undirected arcs
bidirected network	a network composed of directed and undirected arcs
isthmus	an arc whose removal from a network would divide that network into two separate parts
connected network	a network having no isthmus
degree of a node	the number of undirected arcs incident to a node plus the number of directed arcs leaving the node minus the number of directed arcs entering that node
even node	a node having an even degree
odd node	a node having an uneven degree
path	a set of arcs in an undirected network such that every arc terminates where the subsequent arc begins
Euler tour	a path through a network such that every arc is covered exactly once
cycle	a path ending at its point of origin

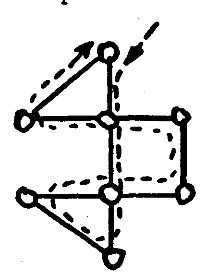
The earliest mention of the minimum arc covering problem is by Euler[59] in]736 at which time he proved theorems showing the existence of an "Euler tour" in either a directed or undirected network. Either type of network possesses an Euler tour if and only if it is connected, and the number of nodes with uneven degrees is zero or two. Since an Euler tour covers every arc once and only once, it is obviously the shortest possible arc covering tour. Examples of networks possessing Euler tours are shown here:



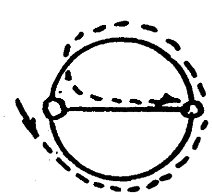
no odd nodes



no odd nodes



no odd nodes

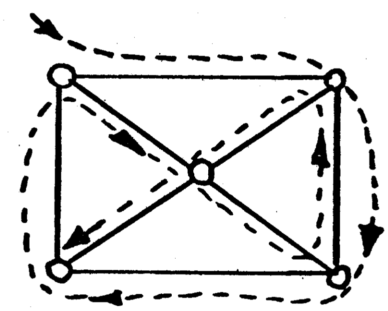


two odd nodes

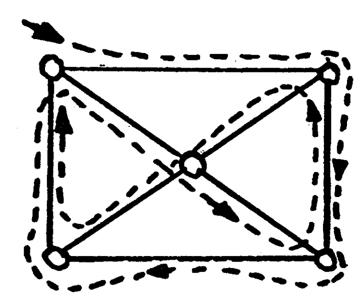
Notice that Euler tours of networks with two odd nodes are not cyclic, that is they do not begin and end in the same place. Also, it should be mentioned, every network having odd nodes will always have an even number of odd nodes. This is because every arc has two end points, and the total degree of any network is two times the number of arcs, which is an even number.

To continue, if a network has more than two odd nodes, it possesses no Euler tour. Thus if every arc in this type of network is to be covered at least once, certain arcs must be covered more than once. This is demonstrated by the following sequence:

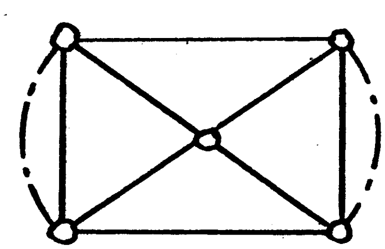
This network has four odd nodes and as such possesses no Euler tour. At least one arc must be covered twice in order to cover all arcs at least once. One possible tour is shown.



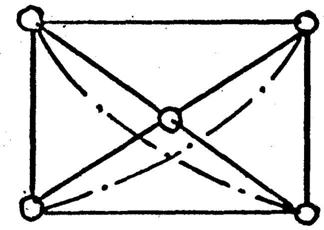
If we add the stipulation that a tour must be cyclic, we see that for every network having 2n odd nodes, at least n arcs must be covered twice. In this case 2n=4 and thus two arcs must be duplicated.



From another point of view[60] what we are really doing is adding "pseudo arcs" to the network where arcs are covered twice, and



by artifically changing odd nodes into even nodes in this way, the modified network then possesses a cyclic Euler tour.



Clearly there are several different ways to accomplish this, each yielding a different cyclic Euler tour, each with a different total arc length. Thus the Chinese Postman Problem takes the form of a game: "How does one optimally pair the odd nodes such that the sum of the pseudo arc lengths is a minimum?"

MATHEMATICAL STRUCTURE

Although the Chinese Postman Problem is highly structured, algorithms for finding the optimal solution are somewhat limited. The mathematical formulation is straightforward.

Minimize $\sum_{i=1}^{N} \sum_{j=1}^{N} C_{ij} X_{ij}$ — (1) objective function

subject to: — (2) conservation of flow, i.e., the number of times travelled into a node equals the number out

$$\sum_{k=1}^{N} X_{ki} - \sum_{k=1}^{N} X_{ik} = 0$$

$X_{ij} + X_{ji} \geq 1$ for all arcs (i,j) A — (3) arc coverage constraint

$X_{ij} \geq 0$ and is integer — (4) non-negativity constraint where

N = the number of nodes in the network
A = the set of all arcs in the network
x_{ij} = the number of times the arc from node i to node j is traversed
c_{ij} = the length of the arc from node i to node j

But the algorithms that are capable of achieving optimality require large computational efforts. If one were to totally enumerate the possible combination of pairs, for example, for a network with M nodes of which N nodes were odd nodes, the following steps and effort would be required:

(a) generate all the shortest paths from each odd node to every other odd node using the network matrix of size M^2. Of all the shortest path algorithms researched[61], the best for this purpose required $(M)(M-1)/2$, or about $M^2/2$ computations.

(b) with this shortest path information an odd node matrix of size N^2 is formed with the shortest path distances as entries. Then all possible sets of pair combinations are evaluated as to their total distance. For N odd nodes this effort would involve

$$1 \cdot 3 \cdot 5 \cdot 7 \cdot 9 \cdot \cdots \cdot (N-3) \cdot (N-1)$$

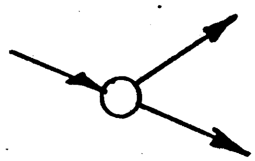
computations. A network having only 20 odd nodes, for example, has 6.5×10^9 feasible soluations. Thus for all practical purposes, total enumeration is highly unsatisfactory as a means of finding the optimal solution.

OPTIMIZATION TECHNIQUES

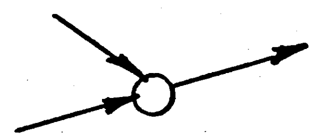
Better techniques have been developed, however, and they are briefly summarized below. For a more thorough review of these one should refer to Stricker[62]. Recall that there are three cases to be considered: the bidirected network (one-way and two-way streets), the directed network (only one-way streets), and the undirected network (only two-way streets).

For the bidirected street network no algorithm presently exists which can solve the arc covering problem. Although Johnson[63] has presented an existence theorem for an Euler tour, his work does not lend itself easily to applications. As yet this particular case remains an open field for investigation.

The directed street network, however, is a case which has been literally solved. All odd nodes in such a network can be categorized into two exclusive groups: excessive or deficient node type. An excessive node is one where there are more arcs leaving a node than entering it, and a deficient node is one where there are less arcs leaving than entering.



"excessive node"



"deficient node"

It has been shown that in order to achieve optimality in the arc covering problem every deficient node must be matched with one and only one excessive node, and vice versa. Thus the Chinese Postman Problem for directed street networks becomes one of optimally matching members of one set in a bipartite graph with members in the other set: a simple "transportation problem" for which there are very good techniques available.

The undirected case has been solved in one sense of the word, yet there still remains the nagging question of efficiency. Murty's[64] "Symmetric Assignment Algorithm" requires the determination of all shortest paths between odd nodes (step (a) above), and then performs a branch and bound technique to the odd node matrix. The efficiency for this second step, however, is data dependent and could be quite poor. Edmonds'[65] "B-Matching" routine is probably the best algorithm today for achieving optimality. It too requires step (a) above, and them employs the dual formulation of the arc covering problem, with much bookkeeping, to reach optimality. Edmonds claims that the efficiency for this second step is no worse than $N^3/3$ iterations.

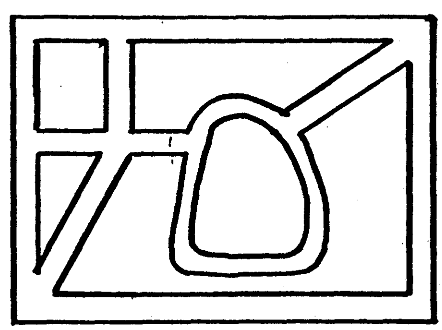
In summary, solving the Chinese Postman Problem using mathematical optimization techniques would require approximately (M)(M-1)/2 computations plus $N^3/3$ iterations of B-Matching. For many practical problems this amount of computation could easily be afforded, however, for large problems the cubic efficiency function provokes one to ask whether there might be more efficient methods. This question leads, then, to the application of heuristics, the subject and implementation of which is the focus of the remainder of this discussion.

HEURISTICS

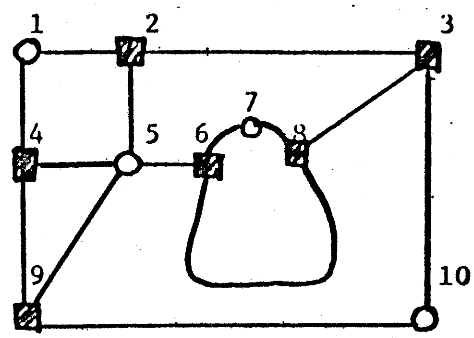
A particular characteristic of the Chinese Postman Problem enables heuristic methods to achieve very good, if not optimal, results with a greatly reduced amount of effort. This characteristic is that very rarely is an odd node (in the optimal solution) paired with another that is relatively far removed from it. In other words, an odd node is usually paired with a neighboring odd node. Thus it is possible to make a very good decision as to which neighboring node should be paired by looking, not at the entire network, but at a localized area, say for example, within five oddnode depths of the node in question. When the node has been paired, the pseudo arcs can be added, the two nodes then become even nodes, and the process is iterated. The only problem that may arise by focussing on a local area is that while sweeping across the network in this fashion a node may be forgotten at one extreme of the network, and then at the end it might have to be inefficiently paired with the remaining odd node at the other extreme. Thus, to prevent this the heuristics should include a global check before making each iteration.

It should be mentioned that the human eye is fairly well suited to play the node pairing game. The mind can "look ahead" at the consequences of a particular pairing possibility, and evaluate the several choices. The computer, however, is even more suited for the bookkeeping effort involved in examining the many series of consequences and counter decisions. Let us try the following sample problem by eye.

First we must convert the street network, with an arbitrary boundary, into a graph network with the odd, even and dummy nodes represented.

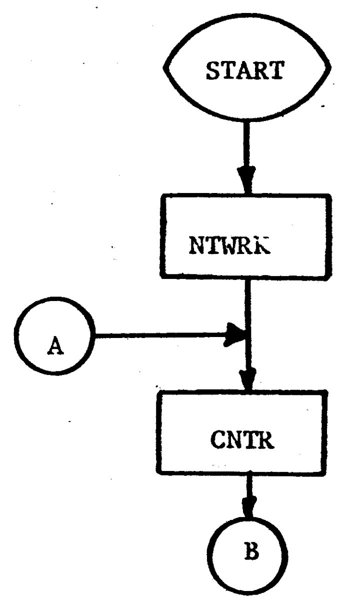


The odd nodes (2, 3, 4, 6, 8, 9) are represented as shaded squares. As we try to pair the odd nodes so that the sum of the arc lengths between the pairs is a minimum, we can rule out several possibilities immediately: (3-4) and (8-9), for example. After some thought, we can pair (4-9), but have difficulty deciding whether to pair (2-3) and (6-8) or (2-6) and (8-3). But if we knew the exact lengths of the arcs, we could easily decide. The solution, if it were the latter, would be represented [(4-9), (2-5-6), (8-3)].

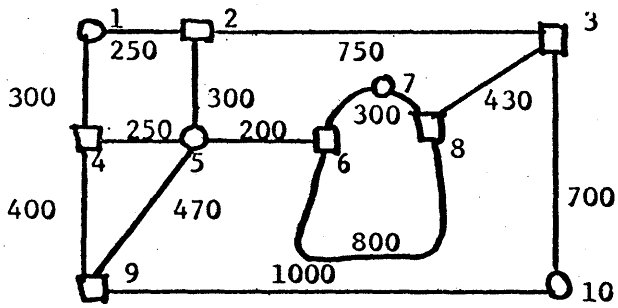


HEURISTIC PROGRAM

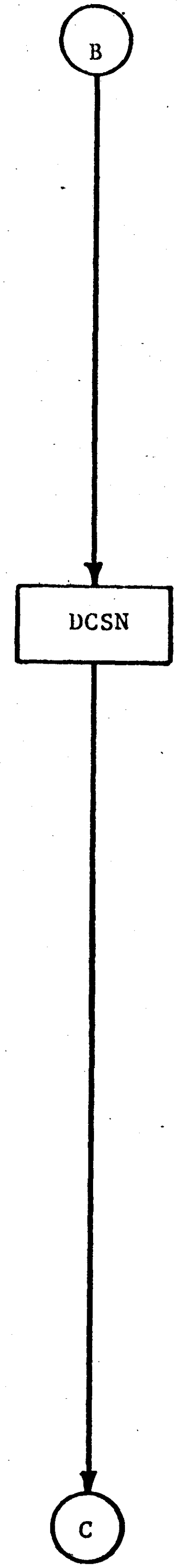
In order to illustrate the explicit heuristics used in the computer program (a listing of which is attached) the procedure used to find the solution to the problem above will be explained step by step. First the data for the street network is read as input in coordinate format. Node types are determined, street lengths are computed or read if non-linear, and this information is then output (see page 114). Then the center of mass of all the active odd nodes is computed and the furthest node from this center is found. This procedure for deciding which node will be paired before others has a "gathering in" effect and prevents



any node from being forgotten on the fringe of the network. In the sample problem the center of mass of the active odd nodes (meaning all six in the first iteration) is near node 5, and thus node 3 is chosen to be examined first because it is furthest from the mass center.



The general decision process takes the following form. If we pair node 3 with 2, there is a cost equal to the path length between them (750 feet), but by pairing 3 with 2, there is a resultant gain of some length because 2 will not be paired with 4, 6, or 9. The minimum possible gain is chosen (200+300=500) conservatively and also because the majority of nodes are paired with their nearest neighbor. But since node 6 can no longer be paired with 2, it is forced to pair elsewhere. Thus the minimum resultant path to its nearest neighbor (i.e., 8) is also considered as a cost due to the original decision. The total cost associated with the decision to pair node 3 with node 2 is considered to be 750-500+300=550. Similarly,



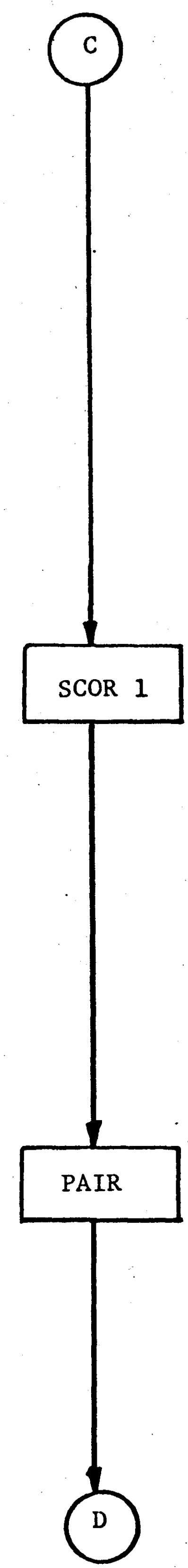
decision (3-8) has a cost of 430-300+450=580, and decision (3-10-9) has a cost of 700+1000 -400+450=1750. Therefore, we can say that if node 3 had the power to decide, it would prefer node 2 to 8 by 30 feet, and node 8 to 9 by 1170 feet.

But a node pairing decision is made only after considering the preferential scores of all other nodes which may be candidates. Thus, after going through the same procedure above for nodes 2, 6, and 8, the following table can be compiled:

node 3	prefers	2	to	8	by	30	and	8	to 9	by	1170
node 2	prefers	3	to	6	by	10	and	6	to 4	by	191
node 8	prefers	3	to	6	by	70	and	6	to 6	by	200
node 9	prefers	4	to	6	by	550	and	6	to 3	by	770

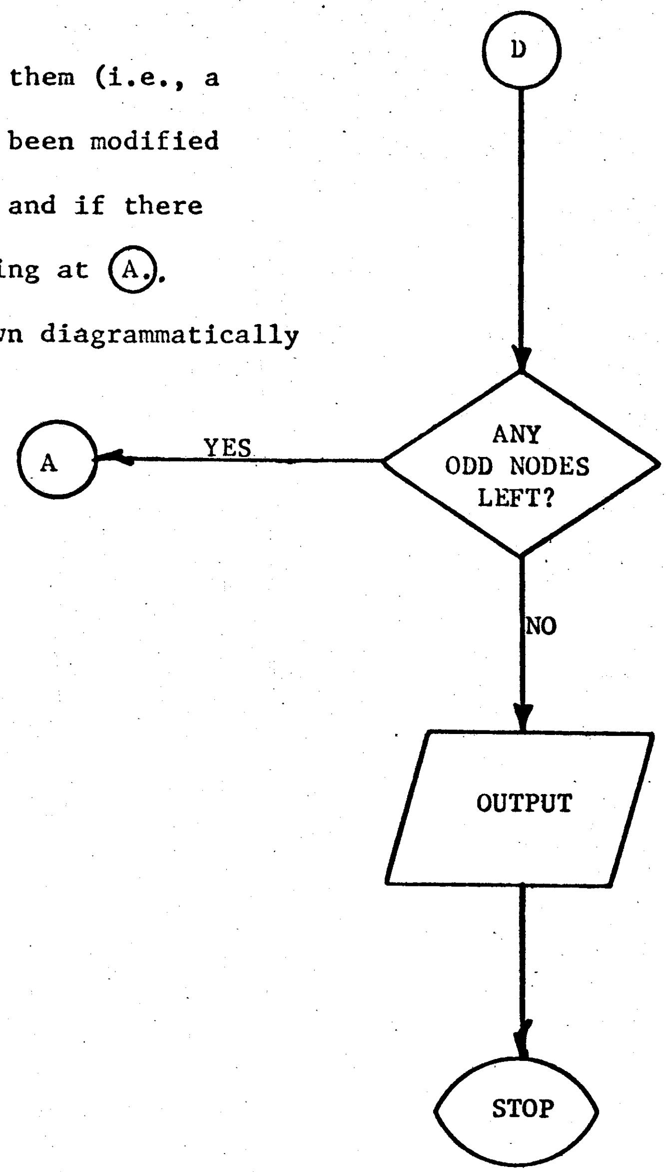
After a rather complicated sorting of preferences with their appropriate decisions (see Subroutine SCOR1 in listing for details), a linear score is computed (no weighting is done) and the decision to pair node 3 with 8 is made.

We pair node 3 with 8 by removing the arcs along the path between them (one arc in this case), which signifies that the path has been covered twice and that it should not be covered again. The active odd nodes 3 and 8 are set to an inactive state, meaning that they are now considered to be



nodes with only two arcs incident to them (i.e., a dummy node). As the network has now been modified we check for other active odd nodes, and if there are some remaining we iterate beginning at (A).

In summary, the sequence is shown diagrammatically on the next page, (Figure 10).



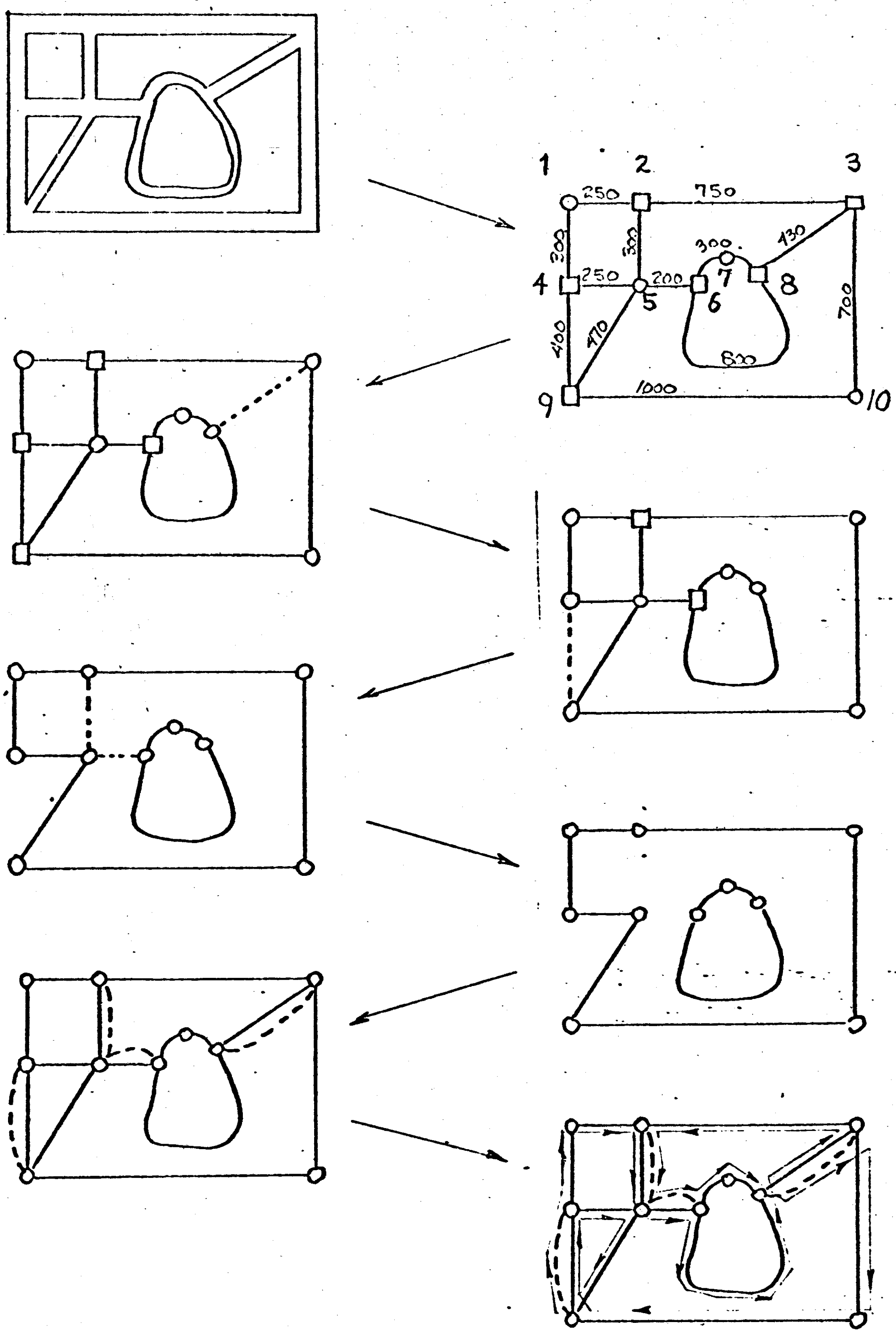


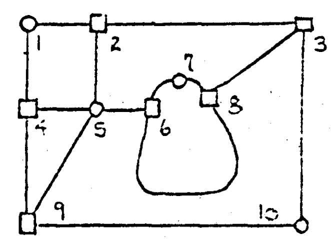
Figure 10: Heuristic Sequence

NETWORK INFORMATION

NODE NO.	XCOORD	YCOORD	NODE	DIST.	NODE	DIST.	NODE	DIST.	NODE	DIST.	KEY
1	0.0	0.0	2	250.0	4	300.0	0	0.0	0	0.0	-1
2	250.0	0.0	1	250.0	3	750.0	5	300.0	0	0.0	1
3	1000.0	0.0	2	750.0	8	430.1	10	700.0	0	0.0	1
4	0.0	300.0	1	300.0	5	250.0	9	400.0	0	0.0	1
5	250.0	300.0	2	300.0	4	250.0	9	471.6	6	200.0	0
6	450.0	300.0	5	200.0	7	150.0	8	800.0	0	0.0	1
7	550.0	200.0	6	150.0	8	150.0	0	0.0	0	0.0	-1
8	650.0	250.0	6	800.0	7	150.0	3	430.1	0	0.0	1
9	0.0	700.0	4	400.0	5	471.6	10	1000.0	0	0.0	1
10	1000.0	700.0	9	1000.0	3	700.0	0	0.0	0	0.0	-1

KEY NOTATION ODD=1 EVEN=0 DUMMY=-1
NUMBER OF ARCS= 14
NUMBER OF ODD NODES= 6
TOTAL LINEAR FEET OF STREET= 6151.

COMBINATORIAL STATISTICS
NUMBER OF MINIMUM PATH COMPUTATIONS FOR ENTIRE NETWORK =0.450000E 02
NUMBER OF POSSIBLE ODD NODE PAIRS = 0.150000E 02
NUMBER OF POSSIBLE PAIR COMBINATIONS = 0.150000E 02



SOLUTION	NODE PAIRS		PATH LENGTHS	PATHS		
	3	8	430.	3	8	
	9	4	400.	9	4	
	2	6	500.	2	5	6

TOTAL DUPLICATE STREET LENGTH = 1330.

CONCLUSIONS

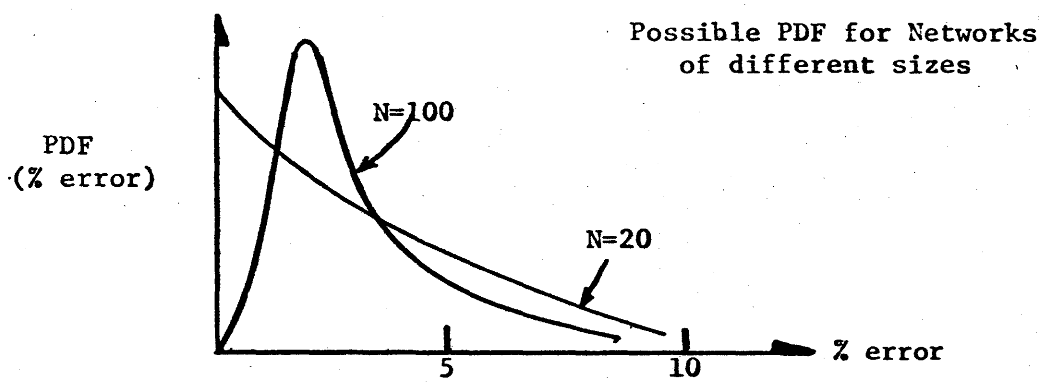
In conclusion, the heuristic program for solving the Chinese Postman Problem for undirected networks is a good one. Its performance on several relatively small sized networks, designed with many snares, indicates a high degree of reliability and accuracy, with respect to the known optimal solutions. Furthermore, the program has the advantage over optimal packages of having a linear efficiency function with respect to the number of odd nodes. In all trials the program has performed equally or bettern in "the odd node pairing" game against numerous graduate students using the hand computations described in Stricker's thesis.[66]

It must be added, however, that there is no guarantee of optimality. In fact, as the number of decision pairs increases with the size of the network, the probability of error becomes very likely, and thus the chances of achieving optimality are rather poor for large networks. This fact detracts little, however, from the utility of the program. Preliminary investigation shows that street networks display the characteristic of having a fairly uniform distribution of feasible Euler tours with respect to their total tour lengths. The nature of the heuristics, by use of the"gathering" effect and of the mutual preference scores of node evaluations of costs versus gains to four node depths, forces solutions toward the low end of this distribution. Furthermore, as the network size increases, the percentage error of the n^{th} "optimal" feasible solution diminishes. For example, the 20 odd network found in the appendix exhibits the following characteristics. There are more than

6.5×10^9 feasible solutions. Of these, five Euler tour lengths are listed below to illustrate the error sensitivity.

Tour length (feet)	Error (feet)	Error/best
25,619 (computer solution)	____	____
25,802	183	0.0071
26,002	383	0.0149
26,250	631	0.0246
26,682	1063	0.0415

With more testing against optimal solutions found by linear programming packages (e.g., Edmonds' B-Matching), comparative data could determine a probability density function of the error ratio for different sized networks (N odd nodes), such as the hypothetical one illustrated below.



In summary, the pragmatic reliability of the program when applied to real problems such as street sweeper routes and other, is felt to be of value, when small errors represent negligible marginal costs.

With respect to efficiency, the number of computations required for each node pairing was not computed. My only measure of efficiency is the length of computation time. On a 16^K IBM 1130 with a cpu time of 3.4 usec, the average iteration for a node <u>pairing</u> was about four seconds with a range between two and six seconds. The real value, however, in efficiency is the program's linear efficiency function, i.e., two seconds/odd node. Furthermore, core requirements are minimal (8^K) as compared to optimal packages which may require at least an N^3 matrix to be core resident.

In summary, I believe it could be useful after more reliability analysis has been done.

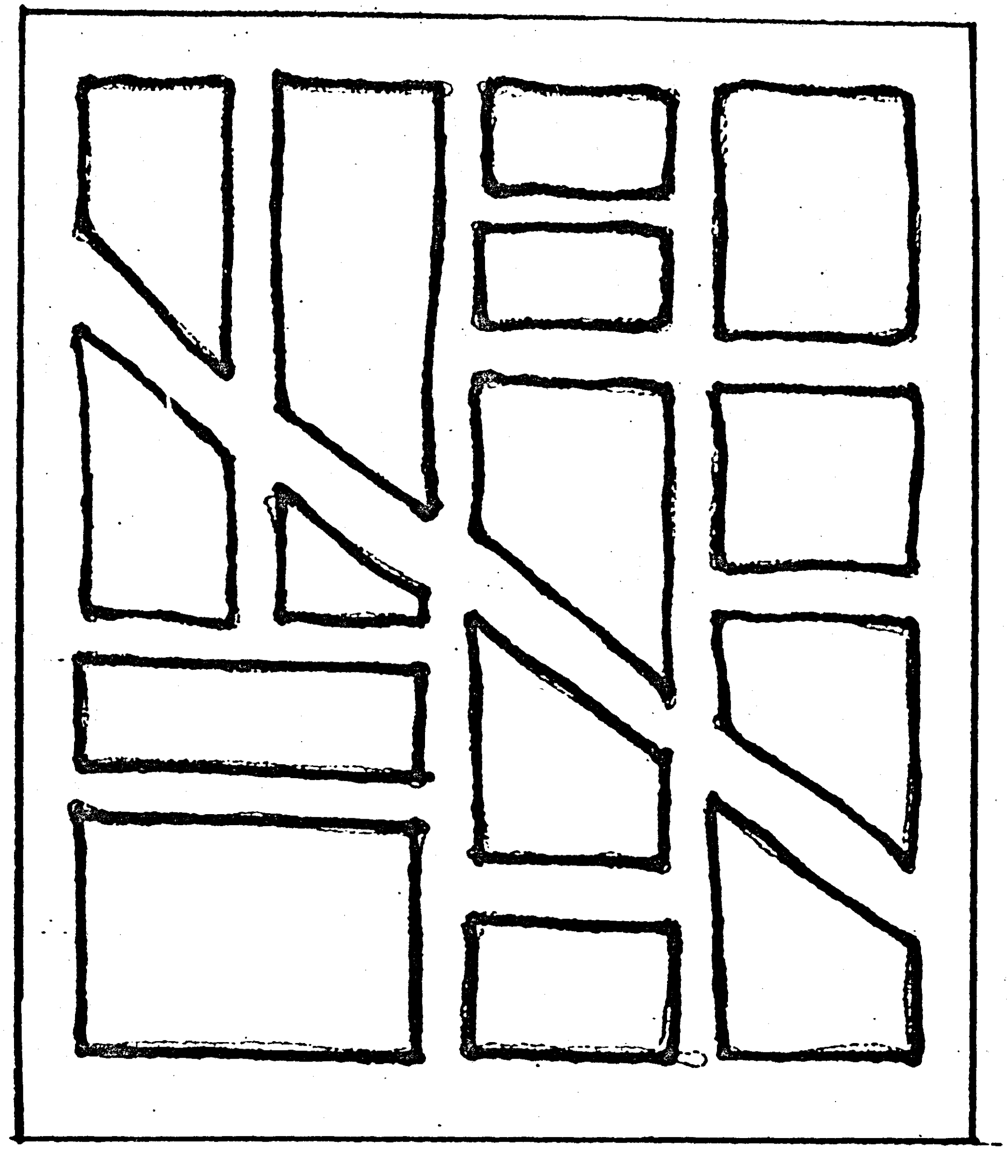
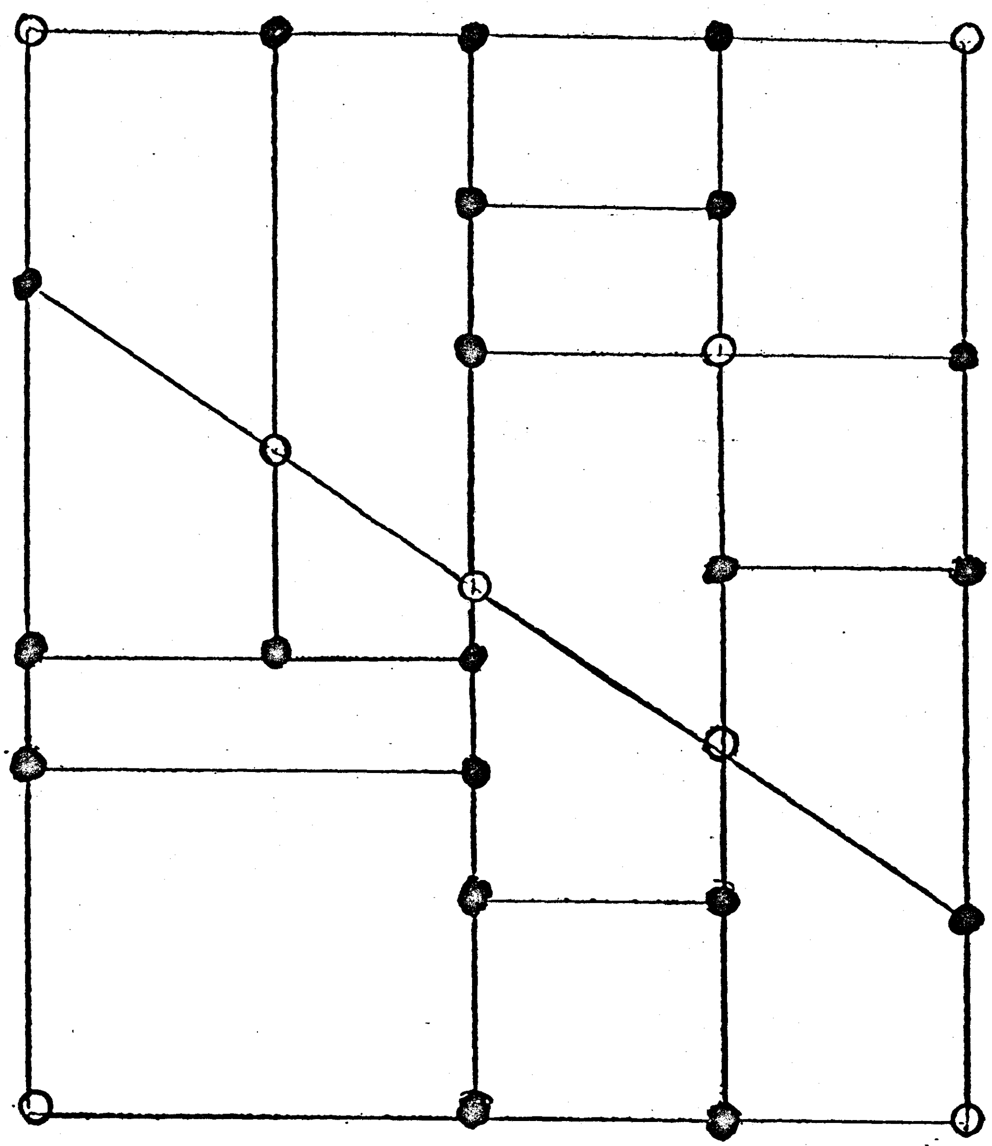


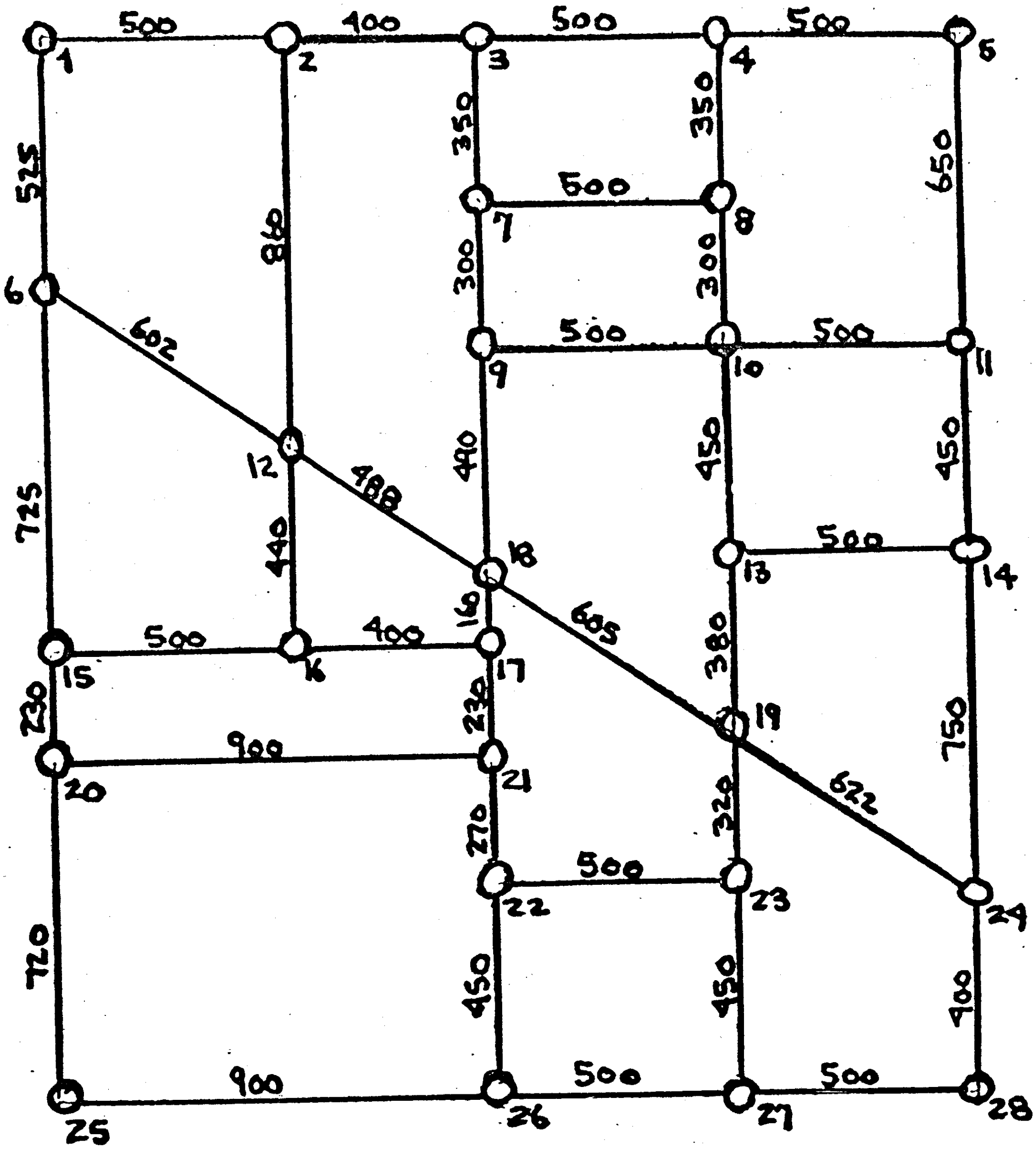
Figure 11: 20 Odd Node Network Example



Challenge

It may be interesting to try an example by eye. Most decisions can be made without knowing the distances exactly, as the arcs are drawn to scale. Furthermore, distances tend to distract one's intuition, rather than help. But if the distances are preferred, they are provided on the next page.

Figure 12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350
650
500
300
300
500
500
602
490
450
450
488
440
500
725
500
400
16
605
380
230
230
900
750
622
320
270
500
720
450
450
900
900
500
500

Figure 13

NETWORK INFORMATION

NODE NO.	XCOORD	YCOORD	NODE	DIST.	NODE	DIST.	NODE	DIST.	NODE	DIST.	KEY
1	0.0	0.0	2	500.0	6	525.0	0	0.0	0	0.0	-1
2	500.0	0.0	1	500.0	3	400.0	12	860.0	0	0.0	1
3	900.0	0.0	2	400.0	4	500.0	7	350.0	0	0.0	1
4	1400.0	0.0	3	500.0	5	500.0	8	350.0	0	0.0	1
5	1900.0	0.0	4	500.0	11	650.0	0	0.0	0	0.0	-1
6	0.0	525.0	1	525.0	12	601.8	15	775.0	0	0.0	1
7	900.0	350.0	3	350.0	8	500.0	9	300.0	0	0.0	1
8	1400.0	350.0	7	500.0	4	350.0	10	300.0	0	0.0	1
9	900.0	650.0	7	300.0	10	500.0	18	490.0	0	0.0	1
10	1400.0	650.0	9	500.0	8	300.0	11	500.0	13	450.0	0
11	1900.0	650.0	10	500.0	5	650.0	14	450.0	0	0.0	1
12	500.0	860.0	6	601.8	2	860.0	18	488.2	16	440.0	0
13	1400.0	1100.0	10	450.0	14	500.0	19	380.0	0	0.0	1
14	1900.0	1100.0	13	500.0	11	450.0	24	750.0	0	0.0	1
15	0.0	1300.0	6	775.0	16	500.0	20	230.0	0	0.0	1
16	500.0	1300.0	15	500.0	12	440.0	17	400.0	0	0.0	1
17	900.0	1300.0	16	400.0	18	160.0	21	230.0	0	0.0	1
18	900.0	1140.0	12	488.2	9	490.0	19	604.6	17	160.0	0
19	1400.0	1480.0	18	604.6	13	380.0	24	622.0	23	320.0	0
20	0.0	1530.0	15	230.0	21	900.0	25	720.0	0	0.0	1
21	900.0	1530.0	20	900.0	17	230.0	22	270.0	0	0.0	1
22	900.0	1800.0	21	270.0	23	500.0	26	450.0	0	0.0	1
23	1400.0	1800.0	22	500.0	19	320.0	27	450.0	0	0.0	1
24	1900.0	1850.0	19	622.0	14	750.0	28	400.0	0	0.0	1
25	0.0	2250.0	20	720.0	26	900.0	0	0.0	0	0.0	-1
26	900.0	2250.0	25	900.0	22	450.0	27	500.0	0	0.0	1
27	1400.0	2250.0	26	500.0	23	450.0	28	500.0	0	0.0	1
28	1900.0	2250.0	27	500.0	24	400.0	0	0.0	0	0.0	-1

KEY NOTATION ODD=1 EVEN=0 DUMMY=-1

NUMBER OF ARCS= 42

NUMBER OF ODD NODES= 20

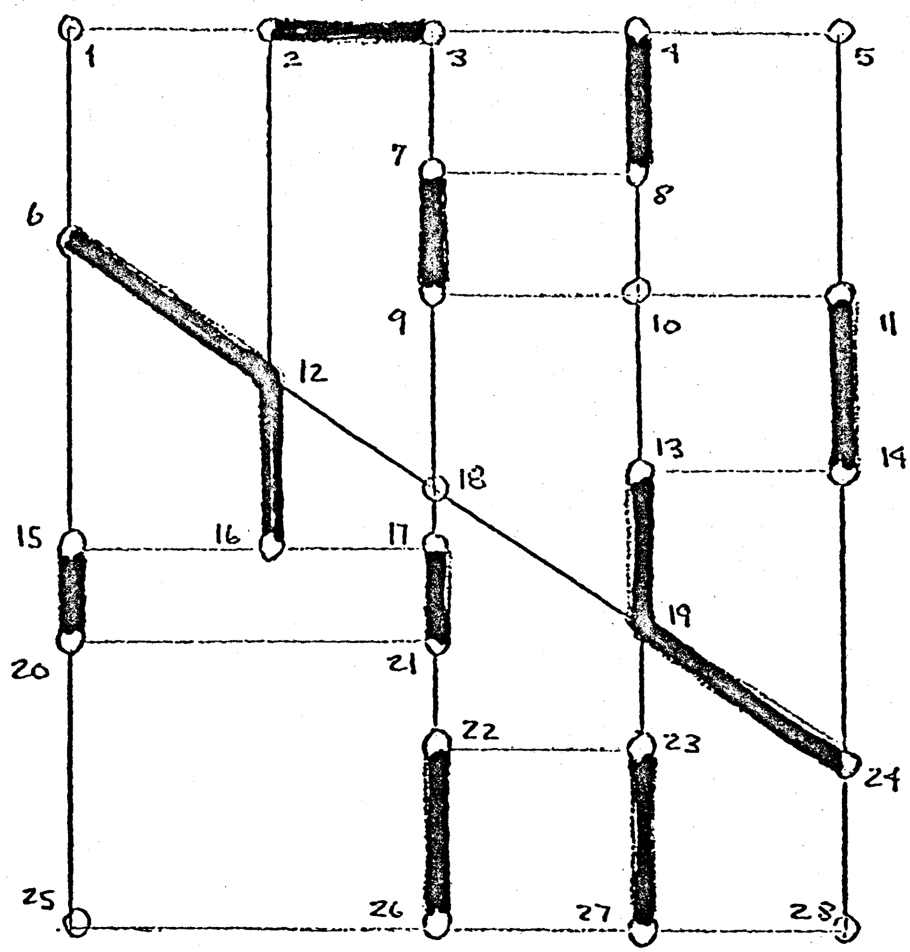
TOTAL LINEAR FEET OF STREET= 20716.

COMBINATORIAL STATISTICS

NUMBER OF MINIMUM PATH COMPUTATIONS FOR ENTIRE NETWORK =0.378000E 03

NUMBER OF POSSIBLE ODD NODE PAIRS = 0.190000E 03

NUMBER OF POSSIBLE PAIR COMBINATIONS = 0.654728E 09



SOLUTION	NODE PAIRS		PATH LENGTHS	PATHS		
	27	23	450.	27	23	
	24	13	1002.	24	19	13
	26	22	450.	26	22	
	20	15	230.	20	15	
	6	16	1041.	6	12	16
	21	17	230.	21	17	
	14	11	450.	14	11	
	2	3	400.	2	3	
	4	8	350.	4	8	
	7	9	300.	7	9	

TOTAL DUPLICATE STREET LENGTH = 4903.

NETWORK INFORMATION (at the end)

NODE NO.	XCOORD	YCOORD	NODE	DIST.	NODE	DIST.	NODE	DIST.	NODE	DIST.	KEY
1	0.0	0.0	2	500.0	6	525.0	0	0.0	0	0.0	-1
2	500.0	0.0	1	500.0	-3	400.0	12	860.0	0	0.0	-1
3	900.0	0.0	-2	400.0	4	500.0	7	350.0	0	0.0	-1
4	1400.0	0.0	3	500.0	5	500.0	-8	350.0	0	0.0	-1
5	1900.0	0.0	4	500.0	11	650.0	0	0.0	0	0.0	-1
6	0.0	525.0	1	525.0	-12	601.8	15	775.0	0	0.0	-1
7	900.0	350.0	3	350.0	8	500.0	-9	300.0	0	0.0	-1
8	1400.0	350.0	7	500.0	-4	350.0	10	300.0	0	0.0	-1
9	900.0	650.0	-7	300.0	10	500.0	18	490.0	0	0.0	-1
10	1400.0	650.0	9	500.0	8	300.0	11	500.0	13	450.0	0
11	1900.0	650.0	10	500.0	5	650.0	-14	450.0	0	0.0	-1
12	500.0	860.0	-6	601.8	2	860.0	18	488.2	-16	440.0	-1
13	1400.0	1100.0	10	450.0	14	500.0	-19	380.0	0	0.0	-1
14	1900.0	1100.0	13	500.0	-11	450.0	24	750.0	0	0.0	-1
15	0.0	1300.0	6	775.0	16	500.0	-20	230.0	0	0.0	-1
16	500.0	1300.0	15	500.0	-12	440.0	17	400.0	0	0.0	-1
17	900.0	1300.0	16	400.0	18	160.0	-21	230.0	0	0.0	-1
18	900.0	1140.0	12	488.2	9	490.0	19	604.6	17	160.0	0
19	1400.0	1480.0	18	604.6	-13	380.0	-24	622.0	23	320.0	-1
20	0.0	1530.0	-15	230.0	21	900.0	25	720.0	0	0.0	-1
21	900.0	1530.0	20	900.0	-17	230.0	22	270.0	0	0.0	-1
22	900.0	1800.0	21	270.0	23	500.0	-26	450.0	0	0.0	-1
23	1400.0	1800.0	22	500.0	19	320.0	-27	450.0	0	0.0	-1
24	1900.0	1850.0	-19	622.0	14	750.0	28	400.0	0	0.0	-1
25	0.0	2250.0	20	720.0	26	900.0	0	0.0	0	0.0	-1
26	900.0	2250.0	25	900.0	-22	450.0	27	500.0	0	0.0	-1
27	1400.0	2250.0	26	500.0	-23	450.0	28	500.0	0	0.0	-1
28	1900.0	2250.0	27	500.0	24	400.0	0	0.0	0	0.0	-1

LISTING OF HEURISTIC PROGRAM

Note:

Programmed in FORTRAN on an IBM 1130.
Core requirements:

a)	program	3956
b)	common	1702
c)	variables	776
		6434 words

```
// FOR
*IOCS(2501 READER,1403 PRINTER)
*ONE WORD INTEGERS
      INTEGER ARC(4,100)
      DIMENSION RAD(4),IRAD(4)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      COMMON  XCORD, YCORD,ARC,DIST,KEY,DUPL
      READ(8,1)ITER
    1 FORMAT(I2)
    2 DUPL=0.
      IFLG=1
      CALL NTWRK(N)
      DO 10 J=1,N
      CALL CENTR(RAD,IRAD)
      IF (RAD(1))8,8,9
    8 IFLG=-1
    9 IN=IRAD(1)
      CALL DCSN(IN,IFLG)
   10 CONTINUE
      WRITE(5,11)DUPL
   11 FORMAT(1X/10X,'TOTAL DUPLICATE STREET LENGTH =',F10.0)
      ITER=ITER-1
      IF (ITER)12,12,2
   12 CALL EXIT
      END
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE NTWRK(NODD)
      INTEGER ARC(4,100)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      COMMON  XCORD, YCORD,ARC,DIST,KEY
C
C     INITIAL
      NODD=0
      SUM=0.
      NARC=0
      DO 50 I=1,100
      XCORD(I)=0
      YCORD(I)=0
      KEY(I)=0
      DO 50 J=1,4
      ARC(J,I)=0
      DIST(J,I)=0.0
   50 CONTINUE
C
C     INPUT ALL NODES AND ARCS OF THE STREET NETWORK
      READ(8,1)NODES
    1 FORMAT(I2)
      DO 3 I=1,NODES
      READ(8,2)  XCORD(I), YCORD(I),ARC(1,I),ARC(2,I),ARC(3,I),ARC(4,I)
    2 FORMAT (2F7.1,4I3)
    3 CONTINUE
C
C     INPUT NON-LINEAR ARC LENGTHS, IF ANY
      READ(8,10) NL
   10 FORMAT (I2)
      IF (NL) 19,19,11
   11 DO 19 I=1,NL
      READ(8,12)NODE1,NODE2,CRV
   12 FORMAT (2I3,F7.1)
      DO 13 J=1,4
      IF(ARC(J,NODE1)-NODE2) 13,14,13
```

```
   13 CONTINUE
   14 DIST(J,NODE1)=CRV
      DO 15 J=1,4
      IF (ARC(J,NODE2)-NODE1) 15,16,15
   15 CONTINUE
   16 DIST(J,NODE2)=CRV
   19 CONTINUE
C
C     CALCULATE LINEAR ARC LENGTHS
      DO 29 I=1,NODES
      X= XCORD(I)
      Y= YCORD(I)
      DO 29 J=1,4
      IF (ARC(J,I)) 29,29,20
   20 IF (DIST(J,I)) 21,21,29
   21 K=ARC(J,I)
      DX= XCORD(K)-X
      DY= YCORD(K)-Y
      SUMSQ=(DX*DX)+(DY*DY)
      DIST(J,I)=SQRT(SUMSQ)
      DO 22 J1=1,4
      IF (ARC(J1,K)-I) 22,23,22
   22 CONTINUE
   23 DIST(J1,K)=DIST(J,I)
   29 CONTINUE
C
C
C     COMPUTE TOTAL NETWORK LENGTH
C     DETERMINE ODD NODES AND/OR DUMMY NODES
      DO 34 I=1,NODES
      DO 30 J=1,4
      IF (ARC(J,I)) 33,31,33
   33 SUM=SUM+DIST(J,I)
      NARC=NARC+1
   30 CONTINUE
   31 IF (J-3) 35,36,35
   35 IF (J-4) 34,32,34
   36 KEY(I)=-1
      GO TO 34
   32 KEY(I)=1
      NODD=NODD+1
   34 CONTINUE
      SUM=SUM/2.
      NARC=NARC/2
```

```
C
C     PRINT NETWORK INFORMATION
      WRITE(5,37)
   37 FORMAT('1'/5X,'NETWORK INFORMATION'/)
      WRITE(5,40)
   40 FORMAT (10X,'NODE NO.',4X,'XCOORD',3X,'YCOORD',3X,'NODE',3X,'DIST.
     $',3X,'NODE',3X,'DIST.',3X,'NODE',3X,'DIST.',3X,'NODE',3X,'DIST.',
     $3X,' KEY '///)
      DO 42 I=1,NODES
      WRITE(5,41) I, XCORD(I), YCORD(I),ARC(1,I),DIST(1,I),ARC(2,I),
     $DIST(2,I),ARC(3,I),DIST(3,I),ARC(4,I),DIST(4,I),KEY(I)
   41 FORMAT(13X,I2,5X,F7.1,3X,F7.1,3X,I2,2X,F7.1,4X,I2,2X,F7.1,4X,I2,
     $2X,F7.1,4X,I2,2X,F7.1,4X,I2)
   42 CONTINUE
      WRITE(5,44)NARC,NODD,SUM
   44 FORMAT(1X/9X,'KEY NOTATION',3X,'ODD=1', 3X,'EVEN=0',3X,'DUMMY=-1',
     $/10X,'NUMBER OF ARCS=',I5/10X,'NUMBER OF ODD NODES=',I3/10X,'TOTAL
     $ LINEAR FEET OF STREET=',F10.0/)
      X=NODES*(NODES-1)/2
      Y=NODD*(NODD-1)/2
      SUM=1.
      DO 55 I=1,100,2
      DX=NODD-I
      SUM=SUM*DX
      IF (NODD-I-1)51,51,55
   55 CONTINUE
   51 WRITE(5,52)X,Y,SUM
   52 FORMAT(10X,'COMBINATORIAL STATISTICS'/15X,'NUMBER OF MINIMUM PATH
     $COMPUTATIONS FOR ENTIRE NETWORK =',E12.6/15X,'NUMBER OF POSSIBLE O
     $DD NODE PAIRS =',21X,E12.6/15X,'NUMBER OF POSSIBLE PAIR COMBINATIO
     $NS =',18X,E12.6/'1')
      WRITE(5,60)
   60 FORMAT(/////10X,'SOLUTION',11X,'NODE PAIRS',3X,'PATH LENGTHS',
     $7X,'PATHS'//)
      NODD=NODD/2
      RETURN
      END
// DUP
*STORE      WS  UA  NTWRK
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE CENTR(RAD,IRAD)
C     SUBROUTINE CENTER COMPUTES MASS CENTER OF ACTIVE ODD NODES AND
C     RETURNS IN DESCENDING ORDER THE N MOST DISTANT ACT ODD NODES FROM
C     THIS CENTER, AND THEIR RESPECTIVE DISTANCES
      INTEGER ARC(4,100)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      DIMENSION DUM(100),IDUM(100),RAD(4),IRAD(4)
      COMMON  XCORD, YCORD,ARC,DIST,KEY
C     N=4
C     INITIALIZE VARIABLES
C        IV1=NO. OF ACTIVE ODD NODES   RAD= RADIUS OF N NODES, DESC. ORD
C        XC=X-CNTR  YC=Y-CNTR          IRAD=FURTHEST N NODE  NAMES
      DO 1 I=1,4
      RAD(I)=0.
      IRAD(I)=0.
    1 CONTINUE
      XSUM=0.
      YSUM=0.
      DENOM=0.
      DXSUM=0.
      DYSUM=0.
      IV1=0
      N=4
C
C     COMPUTE (X0,Y0) FOR ACTIVE ODD NODES
      DO 5 I=1,100
      IF (ARC(1,I))2,6,2
    2 IF (KEY(I))5,5,3
    3 XSUM=XSUM+XCORD(I)
      YSUM=YSUM+YCORD(I)
      DENOM=DENOM+1.
      IV1=IV1+1
      IDUM(IV1)=I
    5 CONTINUE
    6 IF (DENOM-2.)500,500,7
    7 XC=XSUM/DENOM
      YC=YSUM/DENOM
```

```
C
C      COMPUTE RADIUS OF ACTIVE ODD NODES
       DO 15 I=1,IV1
       J=IDUM(I)
       DX=XC-XCORD(J)
       DY=YC-YCORD(J)
       DSQ=(DX*DX)+(DY*DY)
       DUM(I)=DSQ
    15 CONTINUE
C
C      SELECT FURTHEST N NODES
       IF (IV1-N)19,20,20
    19 N=IV1
    20 DO 22 J=1,N
       BIG=0.
       DO 21 I=1,IV1
       IF (DUM(I)-BIG)21,21,23
    23 BIG=DUM(I)
       IBIG=IDUM(I)
       IV2=I
    21 CONTINUE
       DUM(IV2)=0.
       IRAD(J)=IBIG
       RAD(J)=SQRT(BIG)
    22 CONTINUE
       RETURN
 500   IRAD(1)=IDUM(1)
       RETURN
       END
// DUP
*STORE      WS  UA  CENTR
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE DCSN(IN,IFLG1)
      INTEGER PTH(3,13),PTS(3)
      REAL LNIN(3),LNTH(3),MLNTH(3)
      DIMENSION MTRX(4,4),DMTRX(4,2),IPTS(3),MPTH(3,13)
      DIMENSION MPATH(13)
C
      IF (IFLG1)100,1,1
    1 MTRX(1,1)=IN
      DO 30 K=1,4
      IF (MTRX(K,1))30,30,5
    5 IN=MTRX(K,1)
      INA=IN
      CALL PPGEN(IN,LNIN,PTH,PTS)
      IF (K-1)10,6,10
    6 DO 7 I=1,3
      MTRX(I+1,1)=PTS(I)
      MLNTH(I)=LNIN(I)
      DO 7 J=1,13
      MPTH(I,J)=PTH(I,J)
    7 CONTINUE
C
   10 DO 20 I=1,3
      NPASS=1
      IF (PTS(I))20,20,11
   11 INB=PTS(I)
   12 CALL PPGEN(INB,LNTH,PTH,IPTS)
   13 CALL AMIN(LNTH,3,IX,SMALL)
      IF (IX)15,14,15
   14 LNIN(I)=14999.
      GO TO 20
   15 LNTH(IX)=15000.
      IF (IPTS(IX)-IN)16,13,16
   16 IF (IPTS(IX)-INA)17,13,17
   17 GO TO (18,19),NPASS
   18 INA=INB
      INB=IPTS(IX)
```

```
      LNIN(I)=LNIN(I)-SMALL
      NPASS=2
      GO TO 12
   19 LNIN(I)=LNIN(I)+SMALL
      INA=IN
   20 CONTINUE
C
      CALL AMIN(LNIN,3,IX,SMALL)
      MTRX(K,2)=PTS(IX)
      TEMP=SMALL
      LNIN(IX)=16000.
      CALL AMIN(LNIN,3,IX,SMALL)
      MTRX(K,3)=PTS(IX)
      DMTRX(K,1)=SMALL-TEMP
      TEMP=SMALL
      LNIN(IX)=16000.
      CALL AMIN(LNIN,3,IX,SMALL)
      MTRX(K,4)=PTS(IX)
      DMTRX(K,2)=SMALL-TEMP
   30 CONTINUE
C
      CALL SCOR1(MTRX,DMTRX,I)
      DO 50 J=1,13
      MPATH(J)=MPTH(I,J)
   50 CONTINUE
      CALL PAIR(MTRX(1,1),MPATH,MLNTH(I))
      RETURN
  100 CALL PPGEN(IN,LNIN,PTH,PTS)
      CALL AMIN(LNIN,3,IX,SMALL)
      DO 101 I=1,13
  101 MPATH(I)=PTH(IX,I)
      CALL PAIR(IN,MPATH,SMALL)
      RETURN
      END
// DUP
*STORE      WS  UA  DCSN
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE PPGEN(IN,RL,K,VAR)
C     PPGEN GENERATES THE THREE SHORTEST AND UNIQUE PATHS
C     RADIATING FROM THE ACTIVE ODD NODE 'IN' TO OTHER
C     ACTIVE ODD NODES, ALL OF WHICH ARE ALSO UNIQUE
      INTEGER ARC(4,100),S(6,13),VAR(3)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      DIMENSION BRAN(9),IDENT(9,6),RL(3),K(3,13),SV(6)
      COMMON  XCORD, YCORD,ARC,DIST,KEY
      DO 1 I=1,13
      DO 1 J=1,6
      SV(J)=15000.
    1 S(J,I)=0
C
C     EXAMINE THREE BRANCHES FROM ODD NODE 'IN'
      DO 10 I=1,3
      KA=ARC(I,IN)
      S(I,1)=KA
      ICOL=2
      SV(I)=DIST(I,IN)
      KIN=IN
    3 IF (KEY(KA))204,8,10
   10 CONTINUE
      GO TO 500
C
C     IF KA IS A DUMMY OR AN INACTIVE ODD NODE, LINK TO NEXT
C     NODE, ADD DISTANCE, NOTE CONTINUATION, AND TEST AGAIN
  204 CALL DUMMY(KIN,KA,KNEW,A)
      IF (ICOL-14)205,207,207
  205 S(I,ICOL)=KNEW
      ICOL=ICOL+1
      KIN=KA
      KA=KNEW
      IF (KA-IN)206,207,206
  206 SV(I)=SV(I)+A
      GO TO 3
  207 SV(I)=15000.
      GO TO 10
C
```

```
C     FROM KA, A MAX OF  9 BRANCHES MUST BE ANALYZED
C     INITIALIZE BRANCH DISTANCE AND ID ARRAYS AND ROW COUNTER
C     FROM KA, A MAX OF 12 BRANCHES MUST BE ANALYZED.
    8 DO 9 J=1,9
      BRAN(J)=15000.
      DO 9 IJ=1,6
    9 IDENT(J,IJ)=0
      IROW=1
C
C     GIVEN IS KA.  KA IS AN EVEN NODE (4 BRANCHES)
      DO 30 JB=1,4
      JCOL=1
      KB=ARC(JB,KA)
      IF (KB-KIN)12,30,12
   12 IF (KB-IN)13,30,13
   13 BRAN(IROW)=DIST(JB,KA)
      IDENT(IROW,JCOL)=KB
      JCOL=JCOL+1
      KKA=KA
   14 IF (KEY(KB))215,17,29
C
C     IF KB IS A DUMMY OR AN INACTIVE ODD NODE, LINK TO NEXT
C     NODE, ADD DISTANCE, NOTE CONTINUATION, AND TEST AGAIN
  215 CALL DUMMY(KKA,KB,KNEW,A)
      IF (JCOL-6)216,216,219
  216 IDENT(IROW,JCOL)=KNEW
      JCOL=JCOL+1
      KKA=KB
      KB=KNEW
      IF (KB-IN)217,219,217
  217 IF (KB-KA)218,219,218
  218 BRAN(IROW)=BRAN(IROW)+A
      GO TO 14
```

```
  219 BRAN(IROW)=15000.
      GO TO 29
C
C     GIVEN IS KB.  KB IS AN EVEN NODE (4 BRANCHES)
   17 TEMP=BRAN(IROW)
      DO 18 N=JCOL,6
   18 IDENT(IROW,N)=0
      DO 30 JC=1,4
      JDCOL=JCOL
      KC=ARC(JC,KB)
      IF (KC-KKA)19,30,19
   19 IF (KC-KA)20,30,20
   20 IF (KC-IN)21,30,21
   21 BRAN(IROW)=TEMP+DIST(JC,KB)
      IDENT(IROW,JDCOL)=KC
      JDCOL=JDCOL+1
      KKB=KB
   22 IF (KEY(KC))223,23,25
   23 BRAN(IROW)=15000.
      GO TO 25
C
C     BYPASS NON-EVEN NODES, NOTE, AND TEST AGAIN
  223 CALL DUMMY(KKB,KC,KNEW,A)
      IF (JDCOL-6)224,224,228
  224 IDENT(IROW,JDCOL)=KNEW
      JDCOL=JDCOL+1
      KKB=KC
      KC=KNEW
      IF (KC-IN)225,228,225
  225 IF (KC-KA)226,228,226
  226 IF (KC-KB)227,228,227
  227 BRAN(IROW)=BRAN(IROW)+A
      GO TO 22
  228 BRAN(IROW)=15000.
C
```

```
C     START NEW PATH SEARCH
   25 IF (JC-4)26,29,29
   26 ITEMP=IROW+1
      IVAR=JCOL-1
      DO 27 JL=1,IVAR
   27 IDENT(ITEMP,JL)=IDENT(IROW,JL)
   29 IROW=IROW+1
   30 CONTINUE
C
C     SELECT THE MIN PATH AND AN ALTERNATE
      NPASS=1
      IVAR=0
   40 CALL AMIN(BRAN, 9,IVAR,SMALL)
      IF (NPASS-1)42,41,42
   41 IF (IVAR)10,60,46
   42 IF (IVAR)10,10,46
C
C     PLACE THESE IN PRIMARY AND SECONDARY LOCATIONS IN SAVE ARRAYS
   46 GO TO (47,49),NPASS
   47 TEMP=SV(I)
      ICLMN=ICOL-1
      DO 48 MCOL=1,ICLMN
   48 S(I+3,MCOL)=S(I,MCOL)
   49 IROW=I+3*(NPASS-1)
      SV(IROW)=TEMP+BRAN(IVAR)
      BRAN(IVAR)=15000.
      DO 50 JF=1,6
      ICL2=ICOL+JF-1
   50 S(IROW,ICL2)=IDENT(IVAR,JF)
      NPASS=NPASS+1
      IVAR=-1
      GO TO (40,40,10),NPASS
C
   60 SV(I)=15000.
      GO TO 10
C
```

```
C
C     FINISH
C     FIND TERMINAL NODE FOR EACH PRIMARY PATH
  500 DO 53 I=1,3
      DO 51 J=2,13
      IF (S(I,J))51,53,51
   51 CONTINUE
      J=14
   53 VAR(I)=S(I,J-1)
C
C     ARE THERE DUPLICATE TERMINAL NODES
      J=1
      IF (VAR(1)-VAR(2))103,101,103
  101 IF (SV(1)-SV(2))102,102,110
  102 J=2
      GO TO 110
  103 IF (VAR(1)-VAR(3))106,104,106
  104 IF (SV(1)-SV(2))105,105,110
  105 J=3
      GO TO 110
  106 IF (VAR(2)-VAR(3))130,107,130
  107 IF(SV(2)-SV(3))108,108,109
  108 J=3
      GO TO 110
  109 J=2
C
C     FIND MIN SECONDARY PATH
  110 IVAR=0
      SMALL=15000.
      DO 112 I=4,6
      IF (SMALL-SV(I))112,112,111
  111 SMALL=SV(I)
      IVAR=I
  112 CONTINUE
      IF (IVAR)113,130,113
C     REPLACE DUPLICATE BY MIN SECONDARY PATH
```

```
  113 SV(J)=SMALL
      SV(IVAR)=15000.
      DO 114 I=1,13
  114 S(J,I)=S(IVAR,I)
      GO TO 500
C
C     OUTPUT
  130 DO 131 I=1,3
      RL(I)=SV(I)
      DO 131 J=1,13
  131 K(I,J)=S(I,J)
      ICOUN=3
      DO 76 I=1,3
      IF (RL(I)-15000.)76,75,76
   75 ICOUN=ICOUN-1
      VAR(I)=0
      IF (ICOUN)76,79,76
   76 CONTINUE
      RETURN
   79 WRITE(5,80)IN
   80 FORMAT(10X,'NO ACTIVE ODD NODES WITHIN 3 DEPTHS OF NODE ',I3)
      CALL EXIT
      END
// DUP
*STORE      WS  UA  PPGEN
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE DUMMY(KORG,KDUM,KNEW,A)
C     DUMMY ENABLES BYPASSING OF INACTIVE ODD NODES AND DUMMY NODES
      INTEGER ARC(4,100)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      COMMON  XCORD, YCORD,ARC,DIST,KEY
      DO 3 I=1,4
      IF (ARC(I,KDUM))3,10,2
    2 IF (ARC(I,KDUM)-KORG)4,3,4
    3 CONTINUE
      GO TO 10
    4 KNEW=ARC(I,KDUM)
      A=DIST(I,KDUM)
      RETURN
   10 WRITE(5,11)KDUM
   11 FORMAT(5X,'ERROR IN SUBRT. DUMMY, KDUM=',I6)
      CALL EXIT
      END
// DUP
*STORE      WS  UA  DUMMY
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE AMIN(A,N,IROW,SMALL)
C     SUBROUTINE AMIN RETURNS THE MINIMUM VALUE AND ITS ELEMENT NUMBER (IROW)
      DIMENSION A(12)
      SMALL=15000.
      IROW=0
      DO  2 I=1,N
      IF (SMALL-A(I))2,2,1
    1 SMALL=A(I)
      IROW=I
    2 CONTINUE
      RETURN
      END
// DUP
*STORE      WS  UA  AMIN
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE PAIR(IN,PATH,PLNTH)
C     SUBROUTINE PAIR LINKS THE OPTIMAL PAIR OF ACTIVE ODD NODES, SETS
C     THESE TO INACTIVE STATES AND REMOVES ARCS ALONG THE PATH FROM
C     THE NETWORK SEARCH AS THEY HAVE NOW BEEN DUPLICATED ONCE.
      INTEGER ARC(4,100),PATH(13)
      DIMENSION  XCORD(100), YCORD(100),DIST(4,100),KEY(100)
      COMMON  XCORD, YCORD,ARC,DIST,KEY,DUPL
      DUPL=DUPL+PLNTH
      KIN=IN
      I=1
      NODE=PATH(1)
    1 DO 2 J=1,4
      IF (ARC(J,IN)-NODE)2,3,2
    2 CONTINUE
    3 ARC(J,IN)=-ARC(J,IN)
      KEY(IN)=-1
      DO 4 J=1,4
      IF (ARC(J,NODE)-IN)4,5,4
    4 CONTINUE
    5 ARC(J,NODE)=-ARC(J,NODE)
      KEY(NODE)=-1
      IN=NODE
      I=I+1
      NODE=PATH(I)
      IF (NODE)1,6,1
    6 N=I-1
      WRITE(5,7)KIN,IN,PLNTH,KIN,(PATH(J),J=1,N)
    7 FORMAT(30X,I3,2X,I3,5X,F8.0,7X,14I4)
      RETURN
      END
// DUP
*STORE      WS  UA  PAIR
```

```
// FOR
*ONE WORD INTEGERS
      SUBROUTINE SCOR1(M,DM,ITH)
C     SUBROUTINE SCOR1 EVALUATES NODE PREFERENCES AND WEIGHTS
C     AND RETURNS ROW NUMBER OF LOWEST SCORING NODE
      DIMENSION M(4,4),DM(4,2),SCORE(3)
      IN=M(1,1)
C
      DO 13 I=1,3
      SCORE(I)=0.
      IF (M(1,3)-M(I+1,1))11,10,11
   10 SCORE(I)=DM(1,1)
      GO TO 13
   11 IF (M(1,4)-M(I+1,1))13,12,13
   12 SCORE(I)=DM(1,2)+DM(1,1)
   13 CONTINUE
C
      DO 30 K=2,4
      IF (M(K,2)-IN)20,24,20
   20 SCORE(K-1)=DM(K,1)+SCORE(K-1)
      IF (M(K,3)-IN)22,30,22
   22 SCORE(K-1)=SCORE(K-1)+DM(K,2)
      GO TO 30
   24 SCORE(K-1)=-DM(K,1)+SCORE(K-1)
   30 CONTINUE
C
      CALL AMIN(SCORE,3,ITH,SMALL)
      RETURN
      END
// DUP
*STORE      WS  UA  SCOR1
```

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