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Minimizing Water and Sewer System Costs Using TOPAZ

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by

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PREFACE

This report is primarily an edited compilation of two major papers and two independent research papers done by five students in the Urban and Regional Planning Program at Virginia Polytechnic Institute and State University. It is also part of an ongoing research endeavor dealing with TOPAZ (Technique for the Optimal Placement of Activities in Zones). TOPAZ originally was developed in Melbourne, Australia by Brotchie, Sharpe, and Toakley of the Commonwealth Scientific and Industrial Research Organization (CSIRO) in connection with metropolitan water, sewer, and transportation planning being done by the Melbourne and Metropolitan Board of Works (MMBW). The idea was to determine how future land uses in the area should be arranged so as to minimize costs for the above services (these costs already were far exceeding revenues).

The work by the CSIRO group was continued in this country by Dickey, with much support provided by the Urban Mass Transportation Administration. The purpose of this work was primarily to determine how land use might be organized so as to minimize travel (and thus also air pollution from, and energy requirements of, transportation systems). Applications of TOPAZ were made in the town of Blacksburg, Other applications included:

Campus building arrangement (for Virginia Tech)
Hospital ward layouts (for the U.S. Public Health Service)
Layouts of activities around a reservoir (for the U.S. Army Corps of Engineers)

Similar studies have also continued in Australia, and it is hoped that a joint book will be forthcoming on TOPAZ in the next year or so.

The main point to be stressed here is that the work reported in this monograph is one part of an overall endeavor. Thus, relatively little time will be spent describing TOPAZ itself and its major advantages and disadvantages. This has been done elsewhere in sufficient detail (see Bibliography, page 21). The main purpose of this monograph is simply to report on new phases in the theoretical development and practical application of TOPAZ. This monograph stresses in particular (1) the search for an economic benefit criterion for TOPAZ; (2) application of the technique to water, sewer, and corresponding land use planning in Blacksburg, Virginia; and (3) identification of land use control, financial, and organizational mechanisms for bringing to fruition some of the land use arrangement schemes generated by TOPAZ for Blacksburg.

The authors would like to thank the Office of Water Resources Research, U.S. Department of the Interior, and the Virginia Water Resources Research Center for the opportunity to perform this research. We hope that the result of this support is a much wider use of TOPAZ. We would also like to thank Janis McDonald, Melody Fields, Sara Reynolds, Chris Duggins, Debbie Bush, and Dorothy Hall for helping to type much of this manuscript.

John W. Dickey

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ABSTRACT

Planners of physical facilities in urban areas have been hindered in developing beneficial and implementable land use plans. One reason is the lack of knowledge as to which alternative patterns are more beneficial or least costly. It is questionable whether a "finger" land use pattern, or scattered satellite new towns, or continued suburban sprawl represents the most beneficial and/or least costly type of regional development. This type of question is of prime concern in this study, especially insofar as the relationship between (a) costs for water supply and sewage disposal, and (b) arrangements of land uses is concerned.

This study has made use of a mathematical technique known as TOPAZ (Technique for the Optimal Placement of Activities in Zoning). It has been applied to the Blacksburg (Virginia) area, for which some data were already available and a full example was developed (presented partially herein). Cost models for water and sewage service facilities were developed and employed in conjunction with other cost models (e.g., for travel, roads and streets, buildings, and land values) to determine the least cost land use arrangement patterns. Additional studies were made of (1) proper criteria for use in TOPAZ, and (2) organizational, legal, and financial mechanisms for implementing TOPAZ results.

Findings indicate that (1) the minimum cost criterion appears most appropriate, (2) cost models are a definite need in TOPAZ, (3) resulting land use allocations are close to existing development, and (4) implementation mechanisms are very weak.

Part I

INTRODUCTION

As more and more of the nation's activities and facilities center on urban agglomerations, urban land increasingly must be viewed as an important and scarce resource, whose use is of significant public interest.

> The critical issue is how land is to be allocated and managed so that private equities are not abridged while the more general public interest is served. There is an urgency about this because of the extreme interdependence that characterizes urban activities, an interdependence that is dramatically illustrated by problems such as those of smog, traffic congestion, water pollution, and spreading blight. [1]

In the public sector, estimates of how various activities and facilities within the urban area are likely to be arranged in space are at the basis of city planning and development.

> Success of governmental efforts of guiding and controlling land uses depends in no small degree on how well changes in the patterns of settlement and activities have been anticipated; the design of land use policy depends on the local government's estimate of what is likely to happen in the absence of such policies, as well as on the community objectives. [2]

This statement is especially significant when one considers the relationship between land use and physical facility development. Is it less expensive (or more beneficial) to provide public services such as water supply, sewage disposal, highways, and mass transit if the urban area is developed in a "finger" pattern (e.g., The Year 2000 Plan for Washington, D.C. and the existing Stockholm development pattern), or if present suburbanization trends are allowed to continue? Or is it less expenisve (or more beneficial) to have a set of scattered satellite new towns or prohibit development altogether in the urban area and start anew in predominantly rural sections of the country? These types of questions are of prime concern in this study, especially insofar as the relationship between (a) costs for water supply and sewage disposal and (b) arrangement of patterns of land use is concerned.

As a result of these considerations there is an ever increasing interest in urban land use models which are of a predictive nature. However, success of governmental efforts additionally depends upon understanding (1) the consequences of the project activity patterns, (2) the most desirable patterns of activity, and (3) the differences between the two. The land use allocation technique, which is the subject of this report, focuses primarily on all the above items.

The technique also is intended to help speed up the land use planning process itself. The development of land use plans for an urban area is usually a time consuming and expensive process. As a result, the planner often is limited to investigating only a few alternative land use development schemes, and these investigations generally are rather quick and rough. In many instances, the best that can be done is to draw a few sketch plans and determine their probable impacts subjectively. Moreover, the planner is almost always working with the anxiety that more time spent on broad-scale plan development means less time available for the arduous task of completing the final plan in detail.

The planner would be greatly aided if he had a fairly rapid technique that, with a given set of data, would generate and determine some of the consequences of various land use schemes. In those cases where it is possible for him to be more specific about his objectives, he would also be aided by a technique that would generate schemes that were fairly close to optimal in terms of these objectives. Quite obviously, though, the complexity of most urban areas would hinder the development of techniques that would provide anything but first-order approximations of consequences. But then, first-order approximations may be more than adequate for initial sketch planning.

TOPAZ (Technique for the Optimal Placement of Activities in Zones) seems to be of benefit in the sketch-planning stage. It was first used in the Melbourne, Australia, metropolitan area. The basic idea behind TOPAZ, as envisioned by Brotchie, Sharpe, and Toakley, [3,4,5] was to use readily available mathematical allocation schemes to organize land use development in an urban area. Initially, the minimization of public service and travel was the main siting objective, although it was recognized from the start that costs certainly were not the only items of concern. Public service costs included those for water and sewers, local streets, hospitals, and schools, to name a few. A prediction was made of how much would be needed by 1990 for high- and low-density residential land and industrial land. TOPAZ was employed to determine where to allocate the needed land use areas so as to minimize the public service and travel costs. All solutions were constrained so that areas available for development in each zone of the city were not filled above capacity. The minimum costs allocations obtained via TOPAZ proved to have some interesting ramifications for development policies in Melbourne. [4]

STUDY OBJECTIVES

Three major problems in these past planning endeavors with TOPAZ have been (1) lack of accurate knowledge of costs of different services, (2) questions about the theoretical desirability of the benefit-cost criterion utilized, and (3) organizational, legal, and financial difficulties in implementing land use arrangements generated by TOPAZ. The objectives of this study thus became:

1. To develop more sophisticated models for predicting water supply and sewage system service costs for various parts of a prototypical city;

2. To use the cost models developed in (1) in conjunction with currently available cost models for other services (highways, electricity, etc.) and in conjunction with TOPAZ, to determine the difference in costs arising from different patterns of land use development;

3. To determine the sensitivity of minimum cost land use arrangement patterns to accuracy of water supply and sewage system cost estimates;

4. To investigate and evaluate alternative criteria for use in TOPAZ and to determine from past investigations how values for the cost minimization criterion might be expected to vary with city size; and

5. To investigate and evaluate possible organizational, legal, and financial mechanisms for implementing the land use patterns produced by TOPAZ.

Results relevant to objectives (1) through (3) are presented in Part II, to objective (4) in Part III, and to objective (5) in Part IV. Part V contains the overall study results and conclusions.

EXAMPLE APPLICATION OF TOPAZ

To illustrate the use of TOPAZ, we have taken the example involving the Town of Blacksburg, [6] a small but expanding town of 22,000 people (including about 10,000 students in 1970) in southwest Virginia. This town is utilized in the application to be described in the next part.

Blacksburg was divided into 61 zones. These are indicated in Figure 1 along with existing land developments.* Zonal delineation was done, as in many planning studies, primarily on the basis of:

1. slope of the land,
2. depth of bedrock,
3. soil type,
4. availability of existing utilities,
5. existing land use development,
6. natural drainage areas, and
7. man-made boundaries (e.g., U.S. 460 Bypass)

Figure 2 shows the land slopes and Figure 3 shows the proposed water system improvements for the area.

The data for the zonal delineation study were also utilized, in part, in the determination of the per acre establishment capital costs and benefits. Costs were divided into five categories: building unit, water supply, sewage disposal, local streets, and electricity (supplied by local developers and the town). These costs vary, of course, according to land slope, the need to excavate in bedrock, soil type, nearness to existing services, and so on. For example, in zone one, which has a slope range of 12 to 20 percent and bedrock very close to the surface, it was determined from conversations with town officials and local land developers that water and sewer capital costs would be about 120 percent higher than those in the lowest cost zones. Per acre costs also varied with the type of activity or land use being considered. In the case of Blacksburg, 16 activities listed in Table 2 were employed. Examples of the per acre costs used in Blacksburg are presented in the top part of Table 1.

The determination of "benefits" naturally proved to be rather difficult, but it was desirable to indicate the benefits that an activity or land use type would receive from being located in places that had certain amenities, such as a good view of the mountains, nearness to other activities, and good landscaping. As a very rough measure of all these, land values were used. It is felt that this measure is not entirely adequate, but at least it attempts to include some representation of items other than costs. Typical land values are shown in the bottom part of Table 1.

* Some of these 61 zones later were combined in the analysis and thus do not appear in Figure 1.

Figure 1

Zones and Existing Development

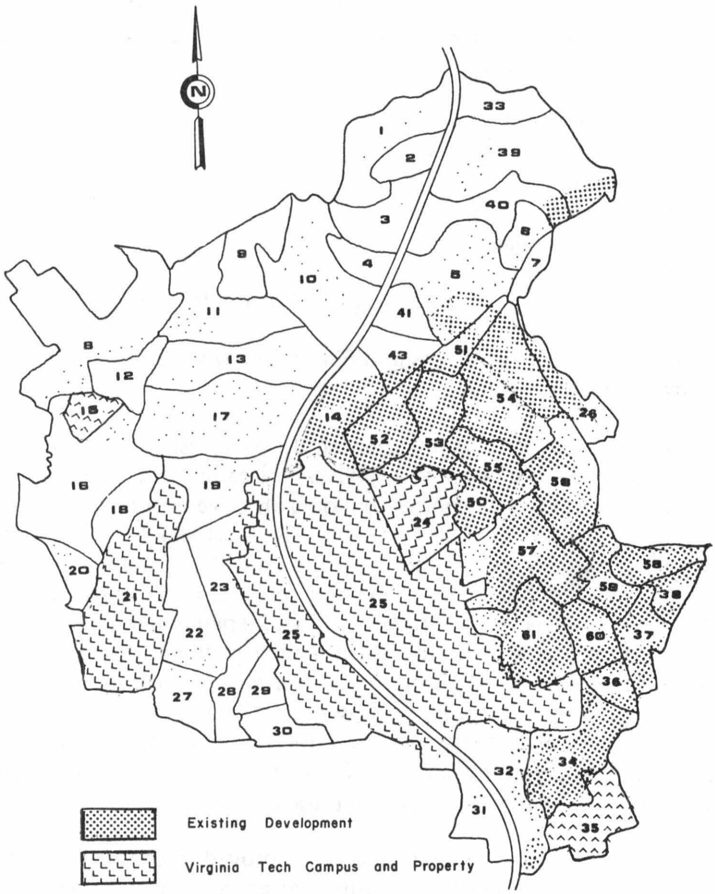
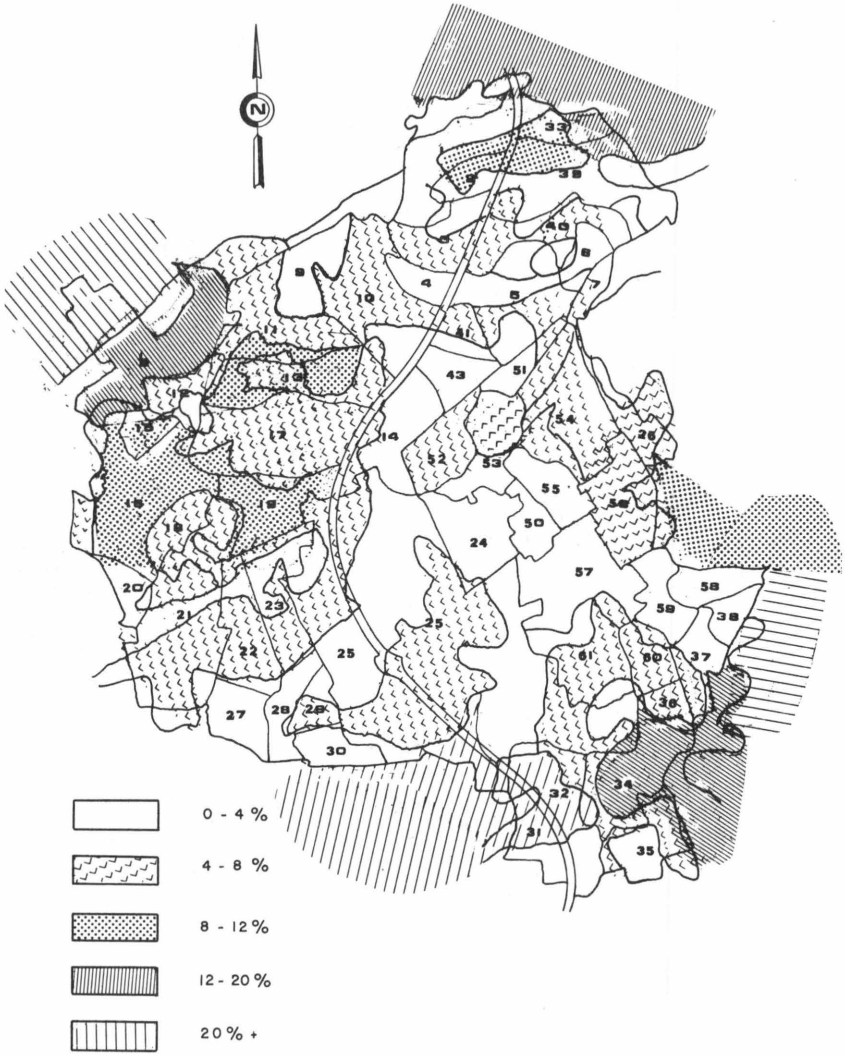


Figure 2

Slope of Land



<u>Figure 3</u>

Priorities of Water System Improvements

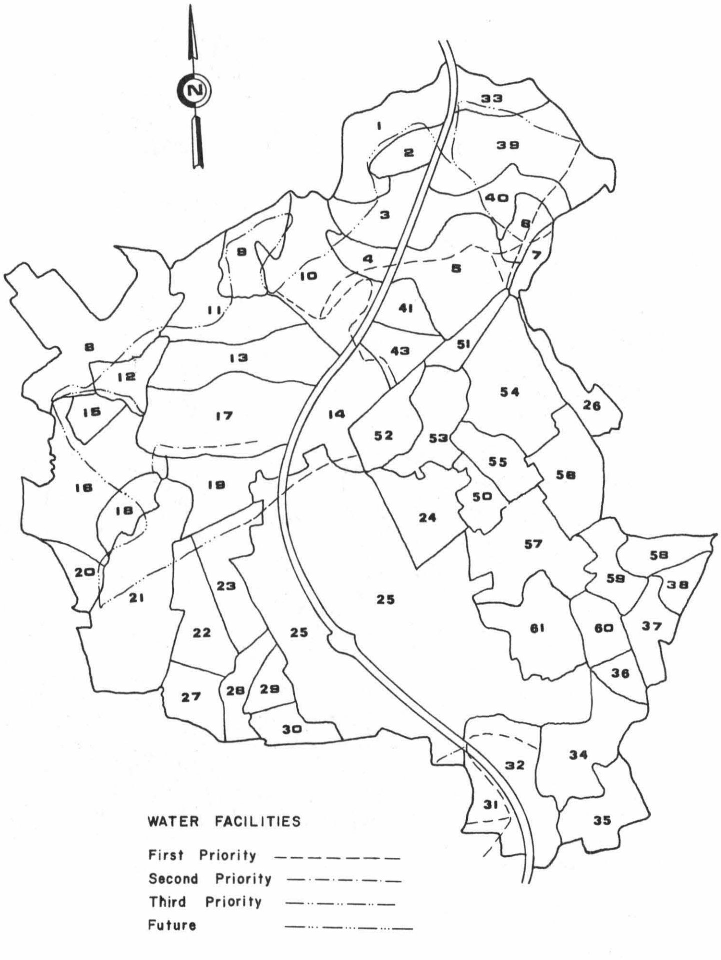


Table 1

Example Establishment Cost and Benefit Values
as Estimated by Local Developers

Building Unit Costs ($/Acre)

Zone	Single Family	Apartments	Townhouses
1	64,000	184,000	144,000
2	54,000	154,000	120,000
3	55,000	155,000	121,000
4	54,000	154,000	120,000

Sewer System Capital Costs ($/Acre)

Zone	Single Family	Apartments	Townhouses
1	2960	3460	3460
2	1810	2310	2310
3	1810	2310	2310
4	1810	2310	2310

Amenity Benefits (Land Values) ($/Acre)

Zone	Single Family	Apartments	Townhouses
1	-1500*	-2250	-2250
2	-1500	-2250	-2250
3	-1500	-2250	-2250
4	-2000	-3000	-3000

*The minus signs indicate negative costs; that is, benefits.

Table 2

Land Use Activity Categories Used in Blacksburg Studies

Code Number	Land Use Activity
A1	Single Family Houses
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public and Semipublic Land
A13	Industry
A14	Streets*
A15	University
A16	Undeveloped Land

*This category was not actually used in the analyses since all areas were gross areas, that is, included local streets, alleys, etc.

A gravity model was utilized to make estimates of zone-to-zone movements based on existing and future amounts of each activity in each zone. The main elements in Blacksburg's transportation system were surveyed and coded in a manner similar to that done in most large scale transportation studies. From this endeavor, interzonal travel costs for each daily trip, predicted by means of the gravity model, were obtained by summing costs on each link on the minimum time path between the zones. These costs were then multiplied by the expected repetitions of that daily trip for each year up to and including the horizon year (1990). Overall travel costs probably could be expected to be relatively low since we assumed a repetition rate of 200 trips per year* and a cost per mile of $0.065.**

The remaining sets of information required for input into TOPAZ were: (1) the estimates of areas available for development in each zone, and (2) the estimates of the areas of each activity (land use) required by the horizon year. The first set of estimates was obtained fairly readily through a typical land use survey. However, there was a definitional question as to what constituted land available for development. Should land with a slope greater than 20 percent be considered available? Is land already dedicated for an industrial park or commercially zoned really available for other uses? These and similar questions became quite perplexing. The approach was to assume almost all vacant land as being available. By acting in this manner, the position was flexible, so that if desired, restrictions of various sorts (e.g., zoning and general policy) could be incorporated to determine the increased costs brought about by these restrictions. In this way, trade-off situations could be set up to see, for example, if the increased costs occasioned by a certain zoning ordinance were more than offset by the anticipated benefits (excluding land values).

The second set of estimates, the amounts of land use areas needed by the horizon year (see Table 2), were perhaps the least reliable inputs to TOPAZ. These areas were obtained by taking the forecasted population figure for the overall region and applying certain proportions to it. In the case of Blacksburg, the population of the town plus the student body was expected to grow from 22,000 people in 1970 to 40,000 people in about 20 years. Of the increase of 18,000 people, 9,000 were expected to be students and the remaining 9,000 permanent residents. In this latter group, it was anticipated that 6,000 would wish to live in single family residences. With 3.2 persons per family and three single family units per gross acre (including streets, etc.), about 626 acres of single family homes would be needed. Similar reasoning was employed to obtain estimates of the other activity areas required. The amounts of these areas could vary somewhat, especially since presently accepted development standards, current zoning density restrictions, and a

***Probably not too low since Blacksburg is a university town and thus has many times during the year when the student body (13,000) is not in full attendance.**

****While low, these these figures can be adjusted and tested via sensitivity analysis using TOPAZ.**

similar pattern of demands for present land use were assumed. But again, some sensitivity analyses can be done to see how land allocations may change; that is, for example, to determine what happens when the demand for townhouses increases while that for single family houses decreases.

Results of the Application to Blacksburg

A series of runs were made with TOPAZ and the Blacksburg data, of which the more important ones are reported below.

TOPAZ requires a feasible solution to be assumed initially. This solution then is upgraded to an optimal one (or close thereto).* In this case, a solution was used that the Town Planner desired to test, particularly because it designated growth in many of the areas for which the Town anticipated providing water and sewer extensions. This initial solution is shown in Figure 4. It includes, predominately, incursions to the northwest side of town in zones 9, 10, 11, 13, and 17. TOPAZ automatically "costs out" all initial solutions, so that the following costs and benefits were obtained:

1.	Total establishment benefits	$\$-3.9 \times 10^6$
2.	Total building unit costs	66.2×10^6
3.	Total water system costs	2.2×10^6
4.	Total sewer system costs	2.1×10^6
5.	Total local street costs	3.1×10^6
6.	Total electric system costs	0.8×10^6
7.	Total travel costs	19.5×10^6
		$\$90.0 \times 10^6$

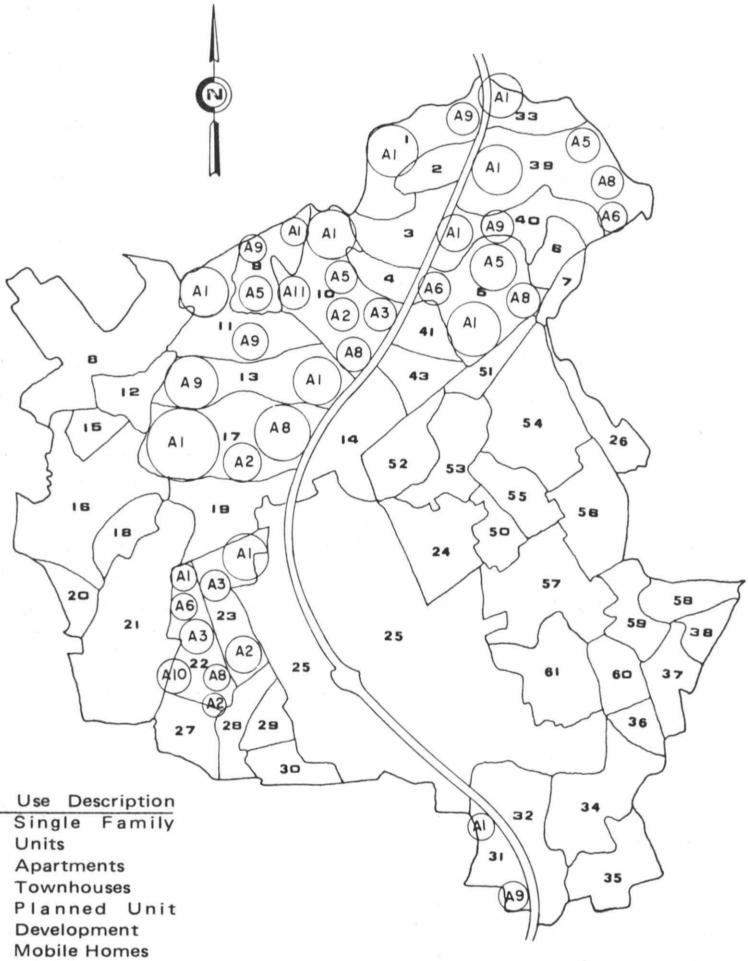
The size of the benefit and cost items should be of interest at this point. The three items for which the town probably would have the least concern (items 1, 2, and 7)** also were the ones of the largest magnitudes. Travel costs were about 22 percent of the total, a relatively low figure since most travel is for short distances in a small town. (Travel costs are more substantial in a large city, however). The total of costs of direct concern to the town was about $8.2 million.

*See Part IV for a small example.

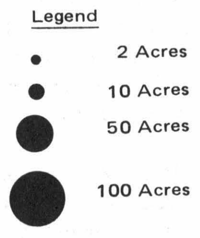
**Concern by the Town probably would be less since the Town does not have to pay for these directly.

Figure 4

Initial Land Use Pattern



Land	Use Description
A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry



The optimal land use pattern generated by TOPAZ starting with the initial solution in Figure 4 is presented in Figure 5. The benefit and cost figures for this pattern were:

1.	Total establishment benefits	$\$-5.8 \times 10^6$
2.	Total building unit costs	65.9×10^6
3.	Total water system costs	2.0×10^6
4.	Total sewer system costs	1.8×10^6
5.	Total local street costs	2.9×10^6
6.	Total electric system costs	0.7×10^6
7.	Total travel costs	16.6×10^6
	Grand Total	$\$84.1 \times 10^6$

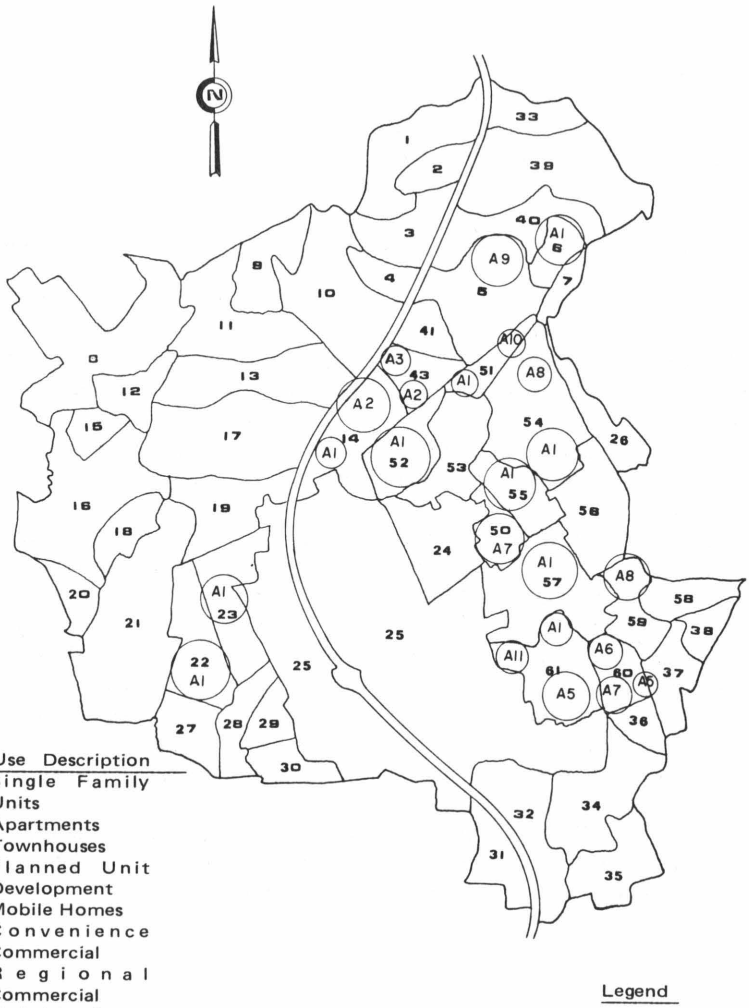
As can be seen, total overall costs were reduced $5.9 million over the initial solution, but it is the makeup of component changes which is of interest. Establishment benefits have risen $1.9 million, indicating that land uses have been placed in areas with more amenities. Travel costs decreased considerably, by $2.9 million, while those costs of direct concern to the town decreased only $0.6 million. Thus, it appears that the town's anticipated strategy of locating some major water and sewer mains on the northwest side will increase their direct costs only slightly but will put an added travel burden on the public and perhaps induce people to go where their benefits would not be quite as great. These results are borne out by a close survey of the zonal allocations shown in Figures 4 and 5.

The proposed expansion to the northwest--zones 9, 10, 11, 13, and 17 in Figure 4--is not found in Figure 5. Instead, much more use is made of the closer-in, currently built-up zones to the north and east of the town. This TOPAZ-generated alternative obviously presents a quite different land use development scheme from the initial one. A warning is in order, however. There may be other benefits not taken into account in TOPAZ that more than make up for the additional costs (and lack of benefits) to be incurred in the initial solution. Yet, the trade-offs are more explicit now: are the additional benefits not considered in TOPAZ worth the extra $5.9 million in costs and foregone land value benefits, $0.6 million of which is in direct costs to the town?

Perhaps only the political process can answer this question, but at least the consequences are clearer, and new and apparently worthwhile alternatives have been generated.

Figure 5

Optimal Land Use Pattern



Land	Use Description
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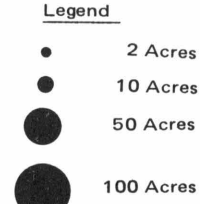
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry



Additional Results

To provide added perspective to the above results and to demonstrate some of the versatility of TOPAZ, an extra set of analyses was made, based on the following objectives:

1. maximize overall costs-benefits,
2. minimize direct town costs,
3. maximize direct town costs,
4. minimize travel costs, and
5. maximize travel costs.

The purpose of the first analysis was to see what the worst land use pattern would be, thereby providing both a datum by which to judge schemes with intermediate cost consequences and an indication of where growth definitely ought not to go. The resultant maximum value was $107.0 million, of which $86.6 million was for establishment costs minus benefits and $20.4 million for travel. We now can see that the town's anticipated scheme would be about 25 percent of the way toward the worst case on an overall cost minus benefit scale. The worst land use pattern itself (not shown) is somewhat as one might expect, with activities allocated to the most expensive peripheral zones.

The scheme with the lowest direct town costs would represent an expenditure of $7.5 million on the four direct cost items. The corresponding maximum scheme would entail an expenditure of $11.3 million. The town scheme, as could be expected, is fairly close to to the lower end of this range. The minimum and maximum travel cost schemes give cost figures of $15.4 million and $20.7 million, respectively. These figures tend to affirm the earlier argument that the town's scheme ($19.5 million in travel) encourages longer tripmaking and thus is more expensive in that line, especially since the areas to be developed under that plan do not have particularly good access. Thus, the town's scheme falls toward the top of the range in this respect. On the other hand, the TOPAZ-generated optimal scheme falls near the minimum. These results all are of some consequence but should be judged only in connection with the assumptions implied in TOPAZ.

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Part II

LAND USE ARRANGEMENTS THAT MINIMIZE WATER AND SEWER COSTS

Introduction

A major problem in water and sewer system planning has been the lack of knowledge concerning the relative costs of alternative patterns of development. To obtain more accurate cost estimates for these services, two models were created. The information gained from the cost models of the water and sewer systems, along with the cost models for other public services, as well as costs of land, building construction, and travel, is utilized in TOPAZ to allocate various land use activities to different sections of a study area. The analyses of water and sewer systems of the area then provide partial inputs into the process of activity allocation throughout the area and, therefore, are only a small part of the total picture. However, the analysis presented here is concerned with water and sewer systems alone.

The design of a water distribution system or of a wastewater collection system is a relatively routine task that utilizes empirical design standards developed over the years by engineers. Such system designs provide information that is normally utilized in determining specific cost estimates for specific projects. The models developed herein are of a more general nature and can be used in conjunction with other planning models to determine where water mains and sewer mains should be developed to realize the least cost in regard to various development patterns. The intended use of these models is to allow planners to deal with areawide development patterns, not to determine specific project costs. In this regard, the specific layouts of lots and subdivisions are not considered although, even on such a small scale, economies can no doubt be achieved by the proper location of activities. This analysis instead is concerned with various zones identified within the study area and with the development patterns in and among these zones.

Although different models are proposed for the water and sewer systems, these services have essentially the same form or structure. Both systems are composed of basic elements that may be identified as sources or headworks (water treatment plants and sewage treatment plants) and of piping networks that distribute water or collect sewage. Although in this analysis both trunk lines and secondary lines are considered to be part of the piping networks, a major focus is placed on the trunk lines. The primary consideration of TOPAZ is the determination of the patterns of development that result in the least cost for all endeavors. The costs are considered variables that depend on the allocation of activities to a zone, on the relationship of the allocations in adjacent zones, and on the overall level of network development that must be accomplished to service any zone. The cost is then prorated to each zone on a per acre basis. These costs for the water and sewer systems take into account economies of scale and economies of staging construction from zone to zone and are used by TOPAZ in the overall allocation of activities.

To illustrate the use of these models, a case study approach has been taken, using Blacksburg, Virginia as an example (see Figures 1, 2, and 3). The existing water systems and wastewater systems have been analyzed to determine their ultimate capacities; the existing demands of the zones have been established from present uses and densities; and the excess capacity of the existing systems has been determined (ultimate capacity minus existing demand equals excess capacity available for use) (see Tables 3 and 4). The key links and nodes of the existing systems have been identified along with physical data such as lengths of links and elevations of nodes (see Figures 6 and 7, and Tables 3 and 5). By utilizing this information, along with estimates of the increased demands imposed on the systems by the total amount of future activities, the planner can utilize the existing system more fully and/or construct new lines.

The complete utilization of existing lines involves only the cost of a connection fee plus some incidental costs for secondary lines. These latter costs vary according to the existing degree of development of the zones (see Table 6). However, after the demand on the system reaches its ultimate capacity, new lines must be constructed or older lines replaced by larger ones. The new construction condition is the cost function that is most significant in the cost models. The cost of new construction depends on the length and size of line required and on other physical elements such as, slope, bedrock conditions, and elevation.

Although the full development of the study area would require increasing the capacities of both water treatment and sewage treatment facilities, the costs of such improvements are not considered as functions of the development patterns. Rather, these costs are viewed as a general cost to the whole study area and as such any per acre cost assigned to one zone would be equal to the per acre cost of any other zone and would merely increase the magnitude of per acre costs for all zones by a single constant. However, since the cost of water and sewer improvements are weighed against the cost of other factors included in TOPAZ, it may be necessary to scale upward the per acre cost of water and sewer improvements by that single constant. This constant was not applied in this analysis, and total cost figures do not show the costs of expanding the treatment facilities.

In illustrating the impacts of the models on activity allocations, seven computer runs were compared in a sensitivity analysis. First, TOPAZ was run with no water or sewer costs included (Figure 8), then with only rough estimates of water costs (Figure 9), then with only rough estimates of sewer costs (Figure 10), and then with rough estimates of both water and sewer

Figure 6

Drainage Divides with New and Existing
Sewer System Links

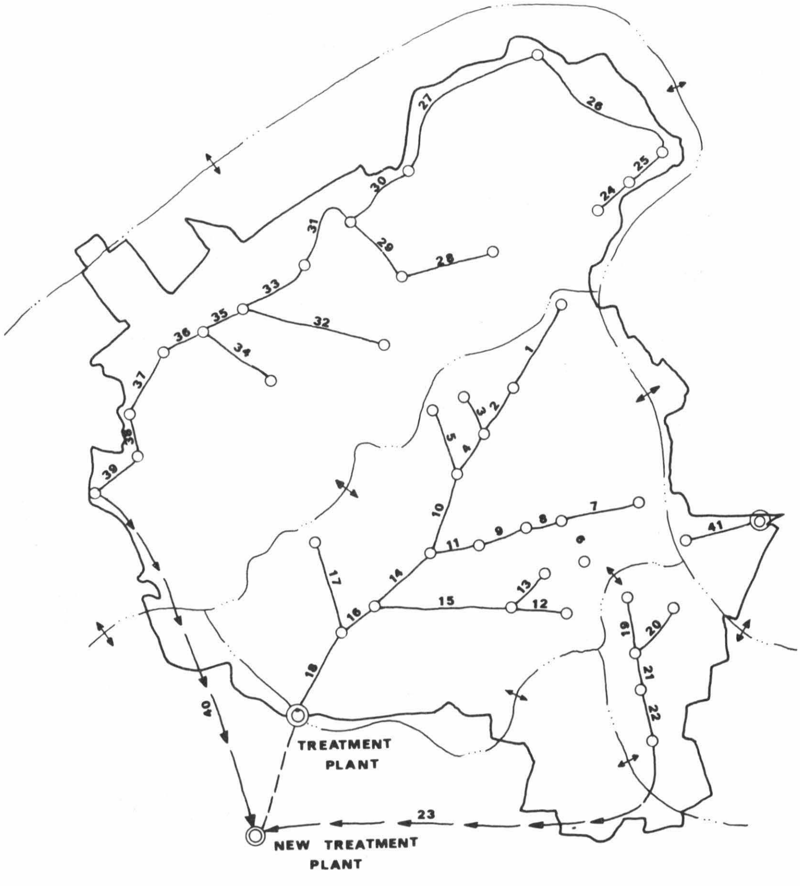


Figure 7

New Water System Links

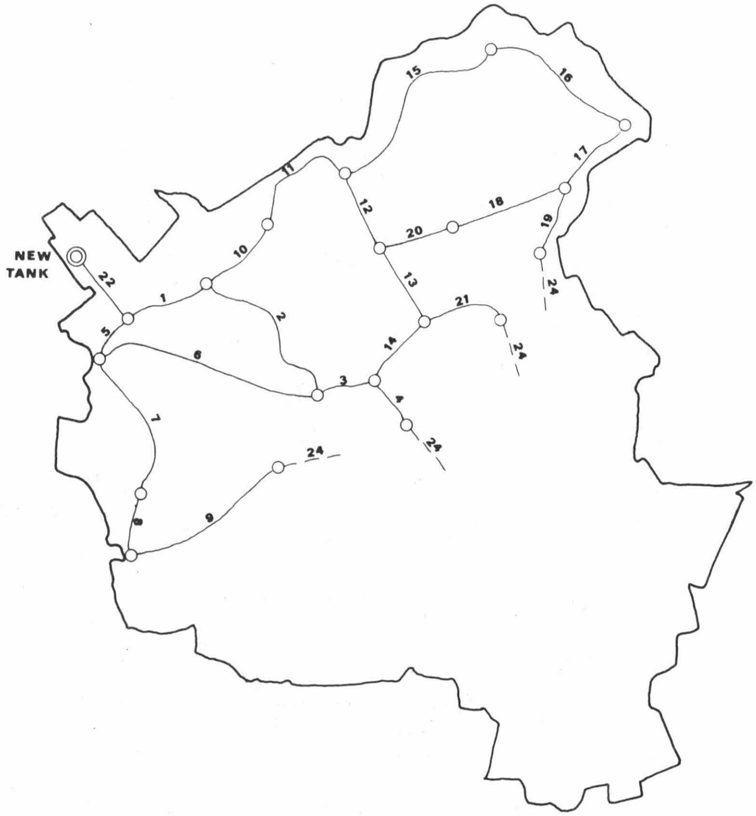


Figure 8

Spatial Layout Including Both Rough Water and Sewer Costs

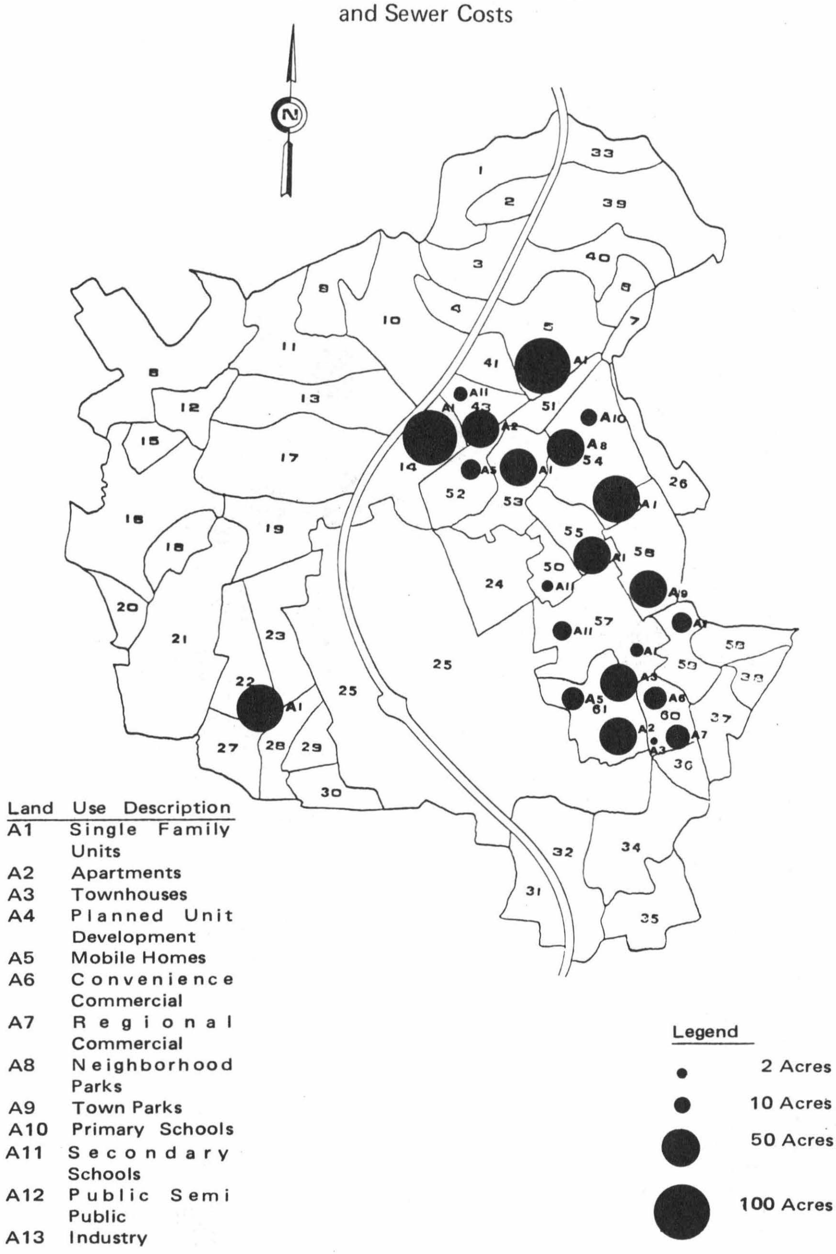
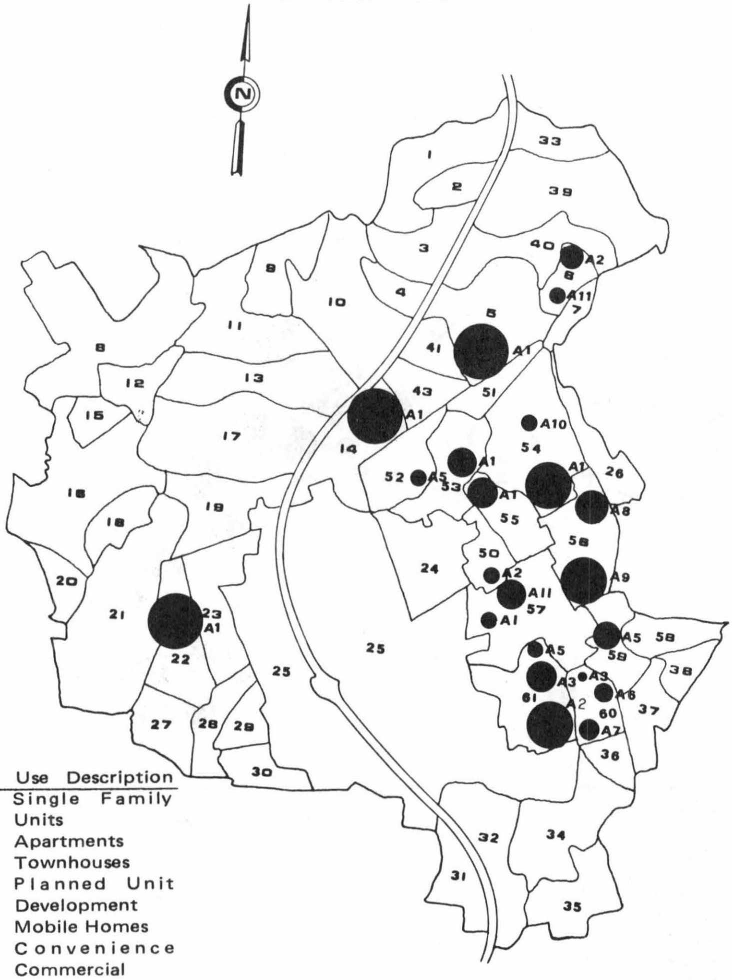


Figure 9

Spatial Layout Neglecting Rough Water and Sewer Costs



Land Use	Description
A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry

Figure 10

Spatial Layout Neglecting Rough Sewer Costs

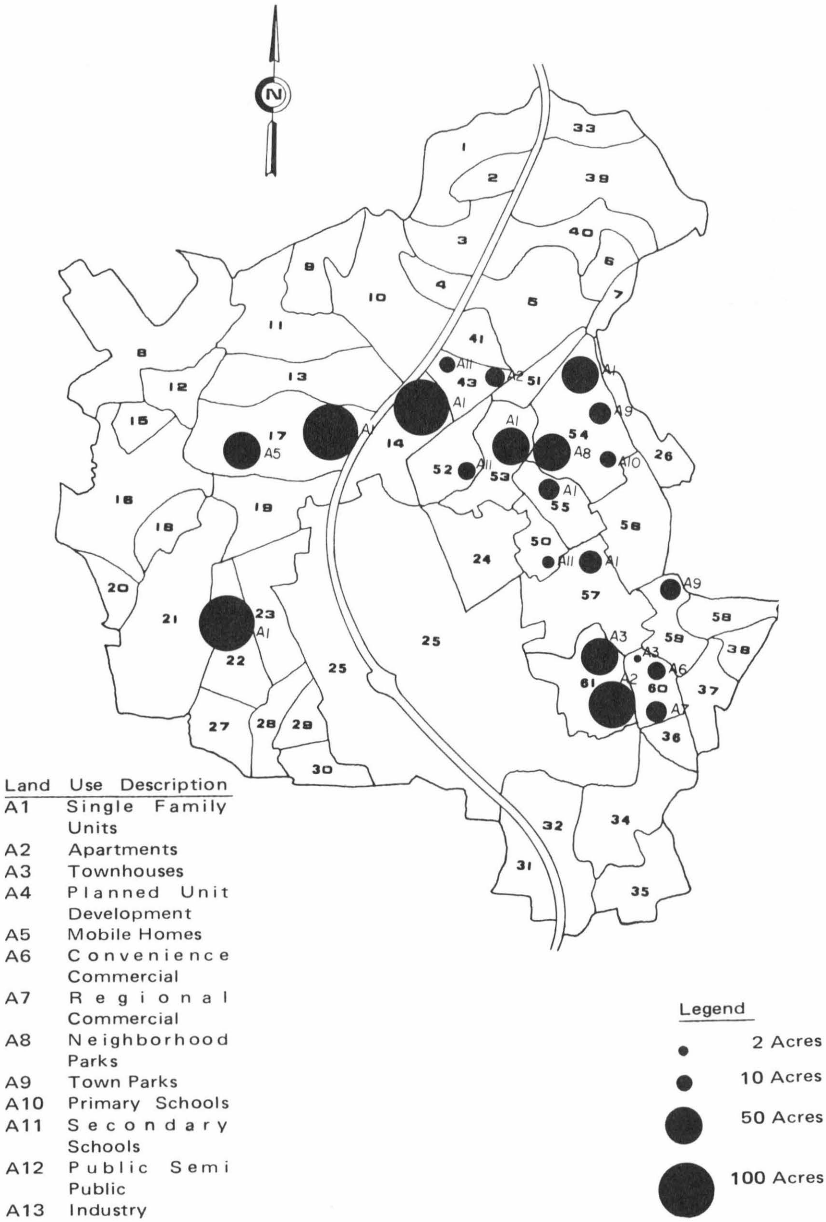


Table 3

Service Lives and Discount Rates Used in Analyses

Cost Factor	Service Life (Yrs.)	Discount Rate (%)	Capital Recovery Factor
Building Unit	25	7	0.08581
Water System	50	10	0.10086
Local Streets	15	10	0.13147
Electric System	25	10	0.11017
Sewer System	50	10	0.10086
Amenity Benefits	25	7	0.08581

Table 4

Physical Data on Sewer System Links

Link	Length (ft)	Size (in.)	Slope	Capacity (MGD)	Initial Status
1	5,000	10	1.00	1.30	Excess Capacity = 0.94
2	1,600	12	1.25	2.60	Excess Capacity = 1.97
3	800	10	2.50	2.10	Excess Capacity = 1.63
4	2,100	15	0.94	4.20	Excess Capacity = 2.95
5	3,600	12	1.80	3.10	Excess Capacity = 2.92
6	1,800	12	2.61	3.70	Excess Capacity = 3.37
7	3,700	10	2.62	2.15	Excess Capacity = 1.73
8	1,200	10	1.08	1.40	No Reserve Capacity
9	3,300	18	0.58	5.10	Excess Capacity = 1.01
10	3,600	15	0.61	3.30	Excess Capacity = 1.60
11	1,300	24	1.00	15.00	Excess Capacity = 10.42
12	2,200	8	2.50	1.15	Excess Capacity = 1.02
13	1,600	15	1.25	4.75	Excess Capacity = 4.42
14	3,000	30	0.40	17.00	Excess Capacity = 11.77
15	5,300	15	0.92	4.10	Excess Capacity = 3.65
16	2,500	36	0.24	22.00	Excess Capacity = 16.37
17	4,300	12	1.51	2.85	Excess Capacity = 2.67
18	5,400	36	0.36	26.00	Excess Capacity = 20.23
19	2,800	8	2.14	1.05	Excess Capacity = 0.79
20	2,600	10	2.69	2.20	Excess Capacity = 1.97

Table 4
(Continued)

Link	Length (ft)	Size (in.)	Slope	Capacity (MGD)	Initial Status
21	1,900	10	2.10	1.90	Excess Capacity = 1.17
22	3,000	12	2.83	3.90	Excess Capacity = 2.87
23	—	P.S.2	—	—	No Existing Link
24	1,400	8	2.86	1.12	No Existing Link
25	2,200	8	0.91	0.69	No Existing Link
26	6,400	8	1.25	0.80	No Existing Link
27	7,700	10	0.78	1.15	No Existing Link
28	4,900	8	0.61	0.56	No Existing Link
29	3,600	10	1.39	1.55	No Existing Link
30	4,500	12	0.44	1.55	No Existing Link
31	3,800	15	0.39	2.65	No Existing Link
32	7,300	10	2.88	2.20	No Existing Link
33	5,000	15	0.30	2.30	No Existing Link
34	4,100	10	2.46	2.05	No Existing Link
35	3,100	18	0.36	4.20	No Existing Link
36	1,200	18	0.25	3.40	No Existing Link
37	4,000	21	0.15	5.56	No Existing Link
38	2,600	21	0.38	6.40	No Existing Link
39	1,900	21	0.53	7.50	No Existing Link
40	—	P.S.	—	—	No Existing Link
41	—	—	—	—	Existing Line with Excess Capacity

Table 5

Zones Contributing Flows to Each Sewer Link

Link	Zones
1	5,51,54
2	5,51,53,54
3	43,52
4	5,43,51,52,53,54
5	14,52
6	57
7	26,56
8	26,50,55,56,57
9	(24)*,26,50,55,56,57
10	5,14,43,51,52,53,54
11	(24)*,26,50,55,56,57
12	61
13	57
14	5,14,(24)*,26,43,50,51,52,53,54,55,56,57
15	57,61
16	5,14,(24)*,26,43,50,51,52,53,54,55,56,57,61
17	23
18	5,14,22,23,(24)*,26,27,28,29,30,43,50,51,52,53,54,55,56,57,61,
19	57,61
20	59,60
21	57,59,60,61
22	34,36,37,57,59,60,61
23	34,36,37,57,59,60,61
24	6,7
25	6,7,40
26	6,7,39,40
27	2,6,7,33,39,40
28	5,41
29	5,10,41
30	1,2,3,4,6,7,33,39,40
31	1,2,3,4,5,6,7,10,33,39,40,41
32	13,17
33	1,2,3,4,5,6,7,9,10,33,39,40,41
34	17
35	1,2,3,4,5,6,7,8,9,10,11,13,17,33,39,40,41
36	1,2,3,4,5,6,7,8,9,10,11,12,13,17,33,39,40,41
37	1,2,3,4,5,6,7,8,9,10,11,12,13,17,33,39,40,41
38	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18,19,33,39,40,41
39	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18,19,20,33,39,40,41

Table 5
(Continued)

40	1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18,19,20,33,39,40,41
41	38,50

*Zone 24 includes an area excluded from the allocation process; the existing flow from this area, however, is assumed to be constant and is used in determining total flows through the system.

Table 6

Physical Data on Water System Links

Link	Length (Ft)	Size (In)	Initial Status
1	3700	10	No Existing Link
2	6600	8	No Existing Link
3	2800	12	No Existing Link
4	2000	12	No Existing Link
5	2400	12	No Existing Link
6	9300	12	No Existing Link
7	6800	10	No Existing Link
8	3300	10	No Existing Link
9	5800	12	No Existing Link
10	3200	10	No Existing Link
11	6100	10	No Existing Link
12	2300	10	No Existing Link
13	3800	12	No Existing Link
14	4400	12	No Existing Link
15	11,300	10	No Existing Link
16	6100	8	No Existing Link
17	4700	10	No Existing Link
18	3900	10	No Existing Link
19	1900	16	No Existing Link
20	3500	10	No Existing Link
21	3000	12	No Existing Link
22	2900	12	No Existing Link
23	--	Tank	No Existing Link
24	--	--	Existing System

costs (Figure 11). The fifth run included only the water model developed in this study (Figure 12); the sixth run included only the sewer model developed in this study (Figure 13); and the final run included both the refined water model and the refined sewer model (Figure 14). The comparison of the mapped results of these computer runs forms the basis of the analysis.

Water and Sewer Facilities

Existing sections of Blacksburg range from densely populated apartment complexes to farms of 100 acres or more and include commercial shopping centers as well as forests. The topography of the town ranges from gently rolling areas to relatively steep mountain sides. Bedrock depths range from zero (rock outcrops) to hundreds of feet. The area contains four major drainage divides, three of which include most of the area of the town. Two of these four drainage areas contain sewer systems and a water system that have been extensively developed. The third large drainage area contains no central sewer system and only a small part of the central water system. The water treatment and sewer treatment facilities are presently working close to their capacities and both will be expanded. Each of the systems is operated by a separate authority that includes as members representatives of the town of Blacksburg and of Virginia Tech. Both the water and sewer systems contain approximately sixty miles of trunk and secondary lines each.

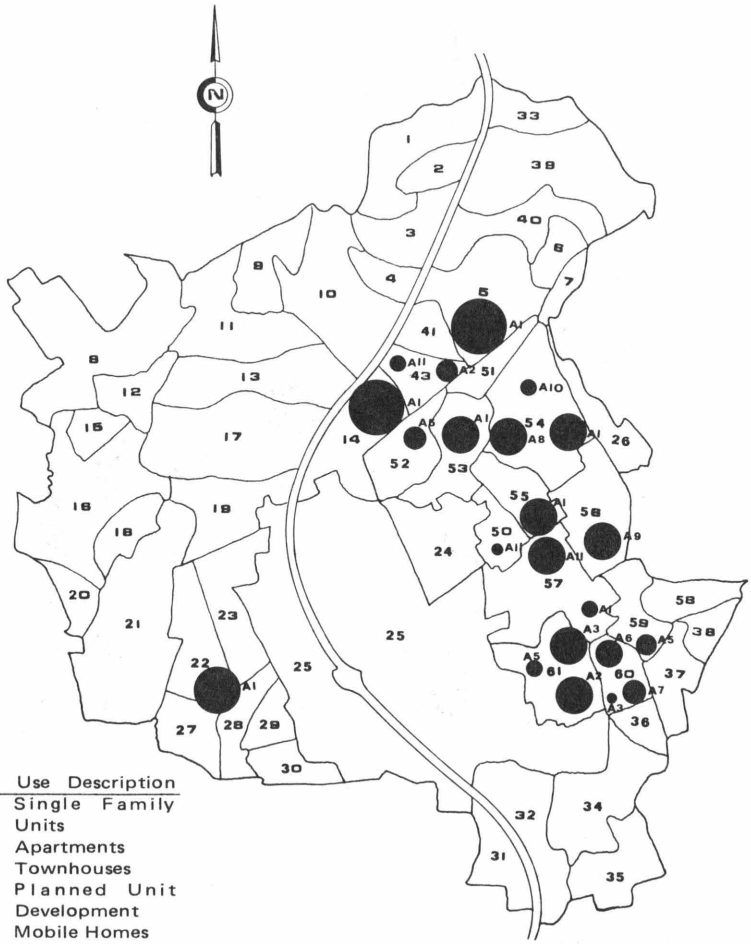
The study area provides a diversity of physical characteristics ideal for testing the sewer model developed herein. In one drainage area there is an existing system with an overloaded treatment facility. Population growth in this area will require expansion of the treatment facilities or pumping to a future regional sewage treatment plant. Another drainage area contains existing lines and a treatment plant adequate for anticipated growth if no sewage is pumped into the area. The third drainage area contains neither lines nor a treatment facility. When sufficient demand is present in the third area, new lines must be constructed and flow pumped to the regional sewage treatment plant. The fourth drainage area contains only a small amount of land included in this analysis and has a small sewer system that is adequate for anticipated growth in that area. In summary, there is an existing system that may need only minor expansion; there is an existing system that may need expansion and structural alteration; and there is an entirely undeveloped area that may require a new system.

Methodology

This project began with a review of relevant literature in the water and wastewater field to find any currently available models for determining the costs of utility systems. Although several models were found that optimized the design of sewer systems or centralized the design of water systems, these models followed the traditional engineering approach to system design rather

Figure 11

Spatial Layout Neglecting Sewer Model Costs



Land	Use Description
A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry

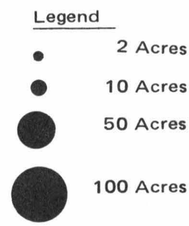
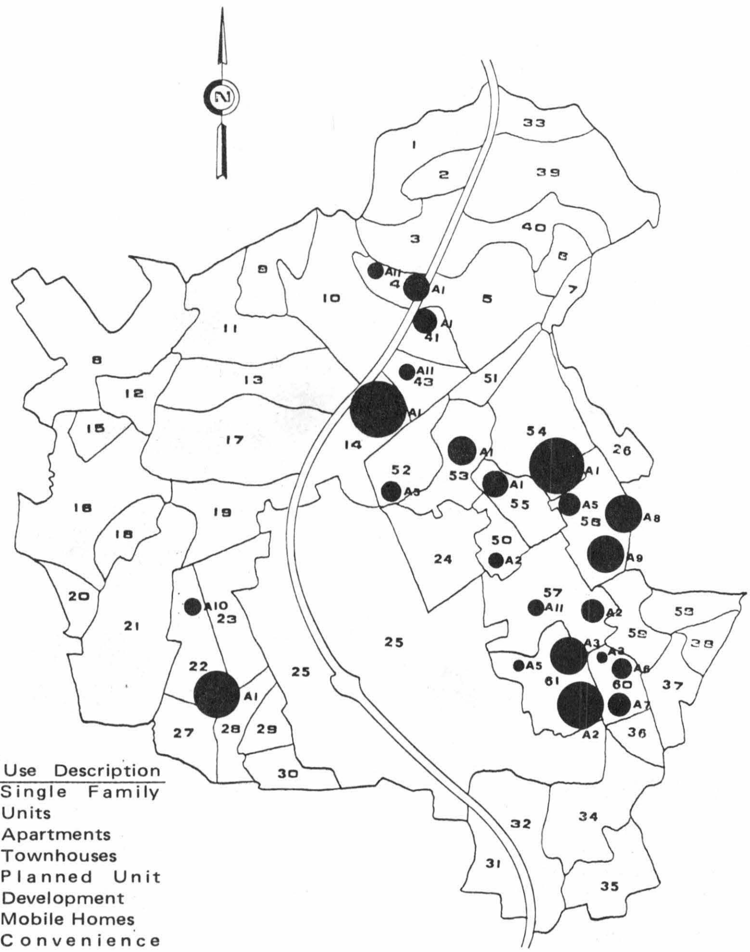


Figure 12

Spatial Layout Neglecting Sewer Model Costs



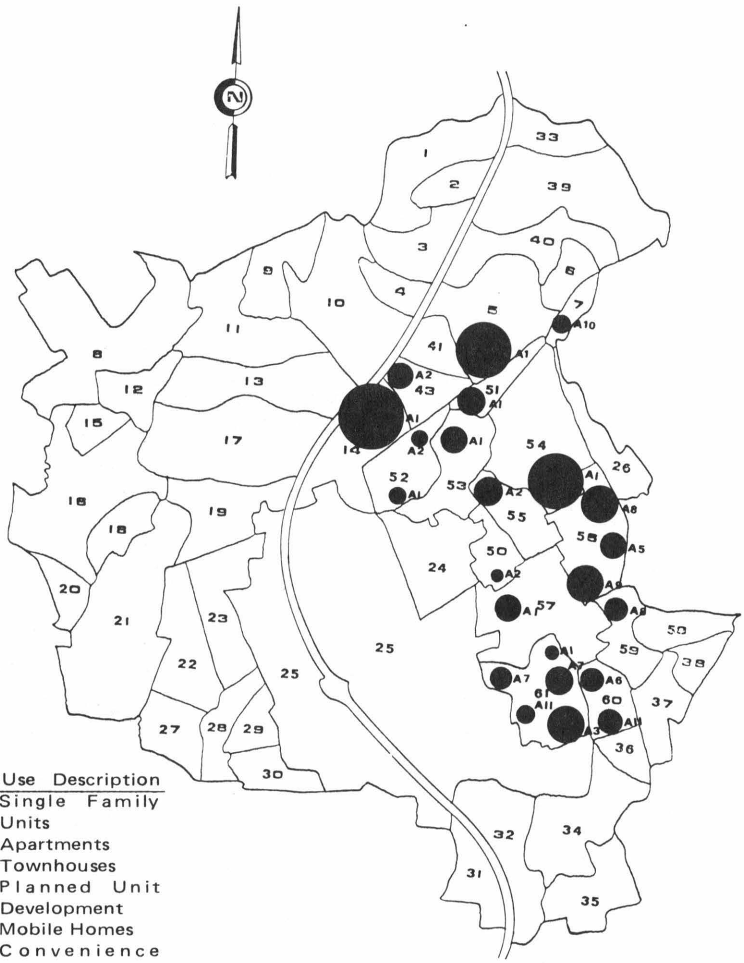
Land	Use Description
A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry

Legend

- 2 Acres
- 10 Acres
- 50 Acres
- 100 Acres

Figure 13

Spatial Layout Neglecting Water Model Costs



Land Use Description

A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry

Legend

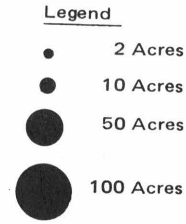
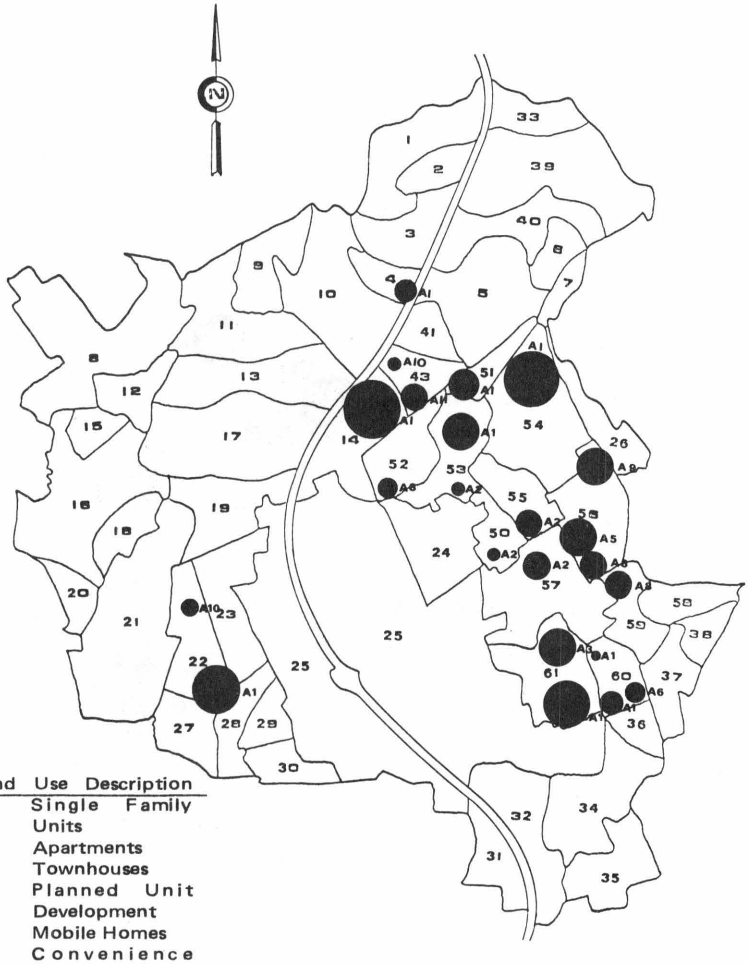
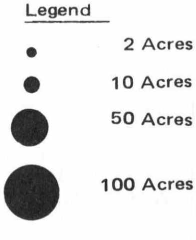


Figure 14

Spatial Layout Including Both Water and Sewer Model Costs



Land	Use Description
A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry



than the more general approach sought for the purpose of this analysis.

Basically, the engineering approach involves the delineation of watershed or drainage areas on the basis of topography, the projection of future population for that drainage area, the determination of the ultimate demand to be placed on the system components, and then, using physical data such as ground slope, length of line required, and subsurface geology, the determination of the pipe size for each link in the system and the cost of the system. This approach is based on a particular population projection for each drainage area from which pipe size and costs are determined.

The approach taken in this study is counter to the traditional approach in that pipe size, cost, and location are used, along with other variables, to determine where population should go in order to minimize system costs.

No usable models were found in the literature; therefore, the next step was to develop a model to fit the requirements of this study. Since it seldom happens that designers are faced with designing purely new systems for urbanized areas, the model developed here depends first upon information regarding the existing systems that may be improved or expanded. Thus the available capacities of existing systems may be utilized before new construction is demanded. The allocation of activities to areas requiring new construction is approached with the objective of minimizing the cost of the new system.

To obtain information regarding system limitations and legal restraints on new construction (particularly regarding wells and septic tanks), interviews were conducted with various officials of the utility authorities in the area, with town officials, and with an official of the County Health Department. In addition, visits were made with members of a consulting engineering firm that has been involved with the design of various components of the utility systems. These interviews and visits yielded pipe sizes, locations and legal constraints but provided little information regarding existing capacities. This lack of information necessitated the design-in-reverse of each major link in the utility systems.

On a set of topographical maps of the area, pipe locations were drawn and the sizes indicated. The elevations of water tanks were determined. With this information and with the length of the lines (as measured on the maps), it was possible to make a rough determination of the ultimate design capacity for any link in the system. Figures on the existing population of each zone, along with estimates of the contributions toward the demand for water and sewer service of commercial activities, were used in the determination of the existing demand being placed on the utility systems. The subtraction from the ultimate capacity of the existing demands gives the amount of capacity not being utilized, and thereby available to accomodate future population growth before new lines or systems would have to be provided. The cost of utilizing the existing systems to their ultimate capacities is composed only of connection fees plus incidental costs (for secondary lines) that vary with the developed or undeveloped status of each zone. After the available capacities of existing systems are utilized, either new trunk lines and collection lines or wells and septic tanks must be constructed. This new construction can be assigned to various zones according to a per acre cost that varies with the activities to be assigned to a zone and with the pattern of development of adjacent zones.

By utilizing the above rationale, computerized cost models were developed and tested, outside of TOPAZ, to insure that they operated in the anticipated manner. The models were then adapted to the data and construction of TOPAZ and were inserted into it as a subroutine. At this point, a sensitivity analysis was conducted, the results of which appear in a following section.

The Basic Cost Model

The models for determining the cost of the water and sewer systems have the same format; therefore, only a general discussion of one model will be included in this section. The principles of the general model will then be applied to both the water and the sewer systems. The operation of the model includes two basic processes of calculating demand and allocating costs, each containing several steps. The following subsections of this paper correspond to the incremental steps of the model as illustrated in Figure 15.

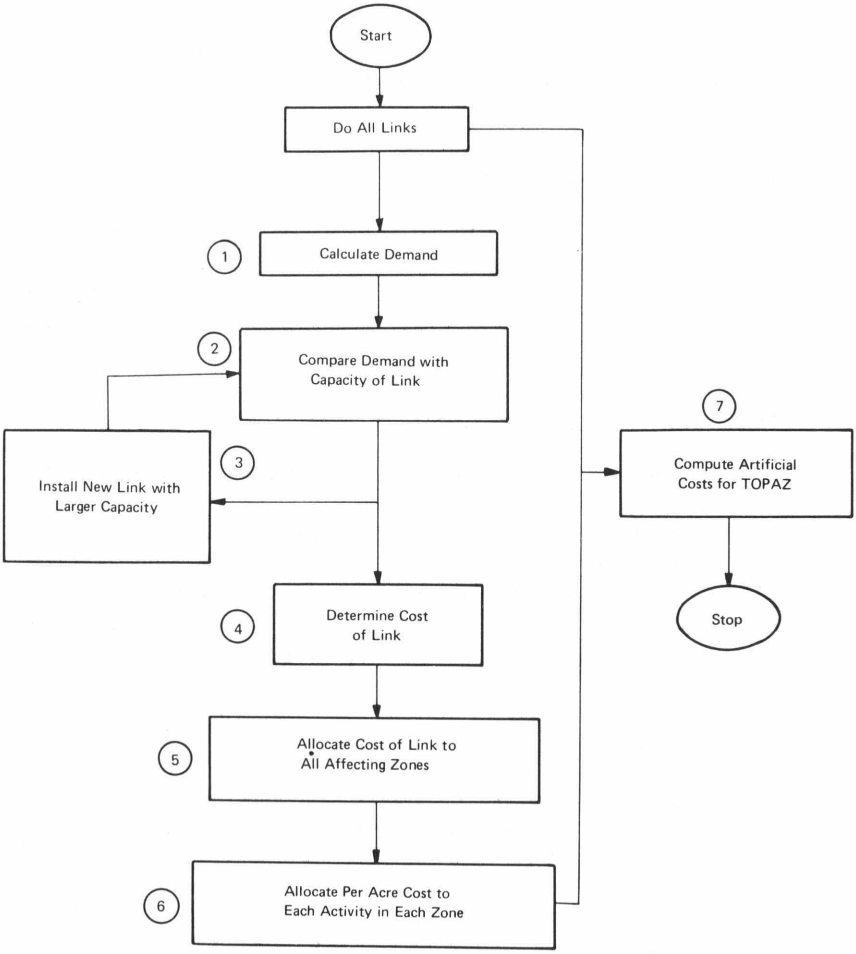
Input data regarding both existing development and development to be allocated to each zone are provided by TOPAZ. For each link in either system, the model then performs the following operations:

1. Calculates demand

   The designs of both sewer and water systems are normally based on the demand created by a certain population level in a study area. Since land uses in TOPAZ are allocated in acres, demand calculations in the cost models have been related to the acres of an activity to be allocated. To simplify matters, demand has been given a common base of one acre of single family development. All other activities are related to single family development by certain factors (see Table 4). Design flows are then calculated by utilizing the number of acres of each allocated activity multiplied by the appropriate factor that relates the flow to the single family base. This procedure utilizes the population densities of each activity found in TOPAZ plus subjective information regarding the flow demanded by certain activities that have no constant density; i.e., parks and commercial activities. For the purpose of this analysis,

Figure 15

Flow Diagram of the Cost Model



equivalent demands are placed on both the water system and the sewer systems. That is, one acre of single family activity places a demand on the water system of 4400 gallons per day and generates 4400 gallons per day of sewage. Although the actual sewage generation may in fact be only 80 percent of water consumption, factors such as groundwater infiltration and other extraneous flows into the sewer systems have been neglected. These additional demands on the sewer system are assumed to make up the difference between water consumption and sewage generation. In summary, the model calculates demand simply by determining the number of acres of each activity to be allocated and multiplying the acreage by some factor to relate flow to a common base. (Table 7)

2. Compares demand with link capacity

This step is included to determine whether existing links have sufficient capacity to handle anticipated demands and, if not, to determine which links need to be expanded, replaced, or constructed. Input data into this step include only the capacities of all existing links and the demand calculated in step 1.

3. Installs a new link with larger capacity

If the demand generated is greater than the existing capacity of a link, the model searches for a suitable alternative for that link and again goes through the comparison routine of step 2. A set of alternatives for each link is provided in advance so that the model has a range of alternatives from which to choose. This model iterates through this step and step 2 until the anticipated demand has been satisfied. If the existing system has sufficient capacity to handle anticipated flow, the model proceeds to step 4.

4. Determines the cost of links

After the demand is satisfied, the cost of all added links is added to the total system cost that is to be allocated to all affecting zones. The cost of each link alternative is provided in advance as input data in the set of alternatives utilized in step 3. Therefore, if a new link is chosen, its accompanying cost is automatically known. The cost of links that are not expanded, replaced, or constructed is assumed to be zero.

5. Allocates cost to all affecting zones

The cost of each network system is allocated to each affecting zone on a per acre basis. This portion of the model is based on the principle that any zone served by, or to be served by, a given link should pay its

Table 7

Sewer Design Criteria

A. Design Flows (Gallons per day per acre of activity)

1.	Single Family	=	4,400
2.	Apartment	=	23,320
3.	Townhouse	=	10,780
4.	PUD's	=	4,400
5.	Mobile Homes	=	9,988
6.	Convenience Commercial	=	5,456
7.	Regional Commercial	=	5,456
8.	Neighborhood Parks	=	1,100
9.	Town Parks	=	1,100
10	Primary Schools	=	2,200
11	Secondary Schools	=	2,200
12	Public and Semi-Public	=	4,400
13	Industry	=	4,400
14	Streets	=	0
15	University	=	0
16	Undeveloped	=	0

B. Maximum Flows

1. For Population = 0 to 10,000 Use Avg. Flow x 4.0
2. For Population = 10,000 to 20,000 Use Avg. Flow x 3.0

C. Pipe Design

Minimum Size = 8 inches
Minimum Velocity = 2 fps
Maximum Velocity = 8 fps
Flow Formula = Manning's Equation ($V = \frac{1.49}{n} \cdot R^{2/3} S^{1/2}$)
n = 0.013 for 12-inch pipe and larger
n = 0.014 for 10-inch pipe and larger
V = Velocity
R = Hydraulic Radius
S = Slope

proportionate share in the cost of that link. The share of the cost assigned to a zone is a function of the degree of development in that zone compared to the degree of development of all zones that are served by the link in question. This rationale is illustrated in Figure 16. In cases where a zone is served by more than one system of links, the zone is divided into fractional areas that are assigned to the different systems (Tables 8 and 9). The cost determination then continues in the normal fashion until all links have been analyzed. At that point, all fractional costs that have been assigned to a zone are added to determine the total cost to be charged to that zone. This total cost is then divided by the total amount of developed acreage in the zone to give a constant cost per acre for that zone. This cost represents the cost of developing one acre of the single family development base in that zone (Table 10).

6. Allocates the per acre cost to each activity in each zone

   The cost assigned to each activity is relative to the flow generation or demand of these activities. As in step 1, where factors were utilized to relate flow to a common base, these same factors are used in this step to allocate proportionate shares of the total cost to each of the activities in each zone.

7. Computes artificial costs for TOPAZ

   The final step in the model operation is the computation of the cost of water and sewer systems in relation to the costs of the other cost factors in TOPAZ.

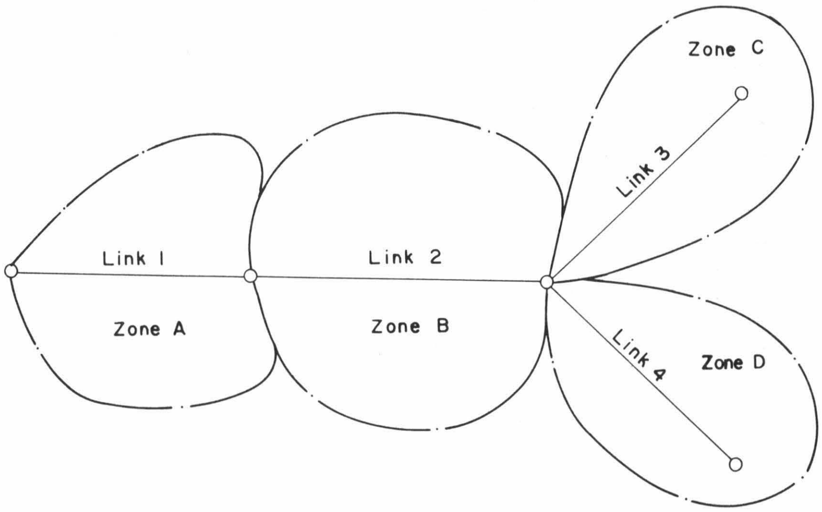
Since cost is a function of pipe size and length, as well as other physical characteristics, the cost of development increases as the distance from the treatment facilities increases. For this reason, the cost model therefore assigns an increasing proportion of the total cost of development to zones further and further from the treatment facilities. The allocation procedure of TOPAZ then attempts to find the land use arrangements that minimize the overall cost of development.

Application of the Models and Results

One purpose of this section is to present graphical, as well as written, results of the application of the cost models for both the water and sewer systems. Figures 8 through 14 illustrate the spatial layout of activities allocated to various zones under different circumstances. Each exhibit also includes the total cost for the water and the sewer system associated with that particular development pattern. It should also be noted that Figures 8 through 11 utilize rough estimates for water and sewer system costs and therefore should be examined as one unit of analysis. On the other hand, Figures 12, 13 and

Figure 16

Cost Allocation Scheme



Zone Proportionate Share of the Cost of $Link_i$*

A 0.25 Link 1
B 0.25 Link 1, 0.33 Link 2
C 0.25 Link 1, 0.33 Link 2, 1.00 Link 3
D 0.25 Link 1, 0.33 Link 2, 1.00 Link 4

*For a given activity this portion is the ratio of the number of developed acres in the zone in question to the number of developed acres in all zones sharing a common link with the zone in question. In the above example it is assumed that each zone has an equivalent number of developed acres.

Table 8

Zones Contributing Demand on Each Water System Link

Link	Zones
1	8,12
2	8,11,12,13,17
3	8,11,12,13,14,17
4	1,2,3,4,8,9,10,11,12,13,14,16,17,18,41,43
5	8
6	8,16,17,18
7	16,18
8	20
9	19,20,22,23
10	11
11	9
12	1,2,3,4,9,10
13	1,2,3,4,9,10,41,43
14	1,2,3,4,9,10,14,41,43
15	1,2,3,4
16	33,39
17	6,33,39,40
18	5
19,	5,6,7,33,39,40
20	10,41
21	1,2,3,4,9,10,41,43
22	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19,20,23, 33,39,40,41,43
23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,16,17,18,19,20,23, 33,39,40,41,43
24	26,27,28,29,30,31,32,34,36,37,38,50,51,52,53,54,55,56,57,58,59,60,61

Table 9

Physical Data on Zones

1. Zones Where There Is Shallow Bedrock
(50% Added to Cost)

1,8,31,32,33,36,37

2. Zones Where There Is Medium Shallow Bedrock
(25% Added to Cost)

2,11,13,16,19,56

3. Undeveloped Zones

1,2,3,4,5,6,7,8,9,10,11,12,13,16,17,18,19,20
28,29,30,31,32,33,34,38,39,40,41,51,58

4. Partially Developed Zones

14,36,37,43,54,56,60

5. Developed Zones

26,50,52,53,55,57,59,61

6. Zones Excluded from Analysis

15,21,24,25,35,42,44,45,46,47,48,49

Table 10

Constant Cost of Developing One Acre of Each Zone*

Zone Status	Bedrock Status		
	Deep	Medium Shallow	Shallow
Sewer System			
Developed	600	750	900
Partially Developed	1000	1250	1500
Undeveloped	1650	2063	2475
Water System			
Developed	600	750	900
Partially Developed	1000	1250	1500
Undeveloped	1500	1875	2250

*These incidental costs are assigned to each zone for the construction or expansion of secondary lines in each system. They are constant for a given zone depending upon the physical characteristics of that zone as outlined above.

14 utilize the cost models developed herein. These costs no doubt are more realistic than the rough costs and turn out to be considerably larger than the rough costs. The larger total cost shown on these latter exhibits should not eliminate them from consideration, however. One of the intended purposes of this analysis is to examine the cost differences between the analyses using rough water and sewer system costs and those using the refined water and sewer models. One spatial arrangement of activities could easily have different costs associated with it depending upon the method by which costs were determined.

All costs for the application were calculated on an annual basis, with different discount rates and service lives associated with each cost factor (see Table 3). The water and sewer systems were assumed to have a 50-year life and to have an associated discount rate of 10 percent. This figure was felt to be typical for most public investments of this sort. The horizon year for the application was 1990, at which time it was expected that the town would have a population of 40,000, including 21,000 students. Of the 6237 acres of land presently vacant in the town, it was anticipated that 1016 would need to be converted to serve the population increase with, for example, 626 acres devoted to single family residences.

Figure 8 displays the development patterns that resulted when both rough water and sewer costs were utilized in the allocation process; that is, when an overall minimum cost was desired. As can be seen in Table 11, which gives cost results for all the applications, water costs for this alternative were $206,595 and sewer costs were $187,895.* Travel costs by comparison are about four times as much, and water and sewer costs combined represent only about 6 percent of the total yearly cost of $6,864,700.

If the rough costs in Figure 7 (based on estimates by developers and real estate agents) are accepted, the cost for water and sewer facilities (plus interest) amounts to only $10 per capita per year--certainly not that much of an expense to worry about. Note also that water and sewer costs are about equal, implying that neither should be given planning preference over the other.

Insofar as resulting land use arrangements are concerned, the obvious pattern in Figure 7 is toward agglomeration in and around existing land uses in town. This is the result of low building and travel costs in the closer-in areas. The only exception appears to be the allocation of a large quantity of A1 (single family units) in zone 22 (see map, Figure 17) in the southwest part of the area. This exception is somewhat imaginary, however, since Virginia

*These and all cost figures to follow have no more than two significant digits even though more non-zero digits are presented.

Figure 17

Spatial Layout of Zones

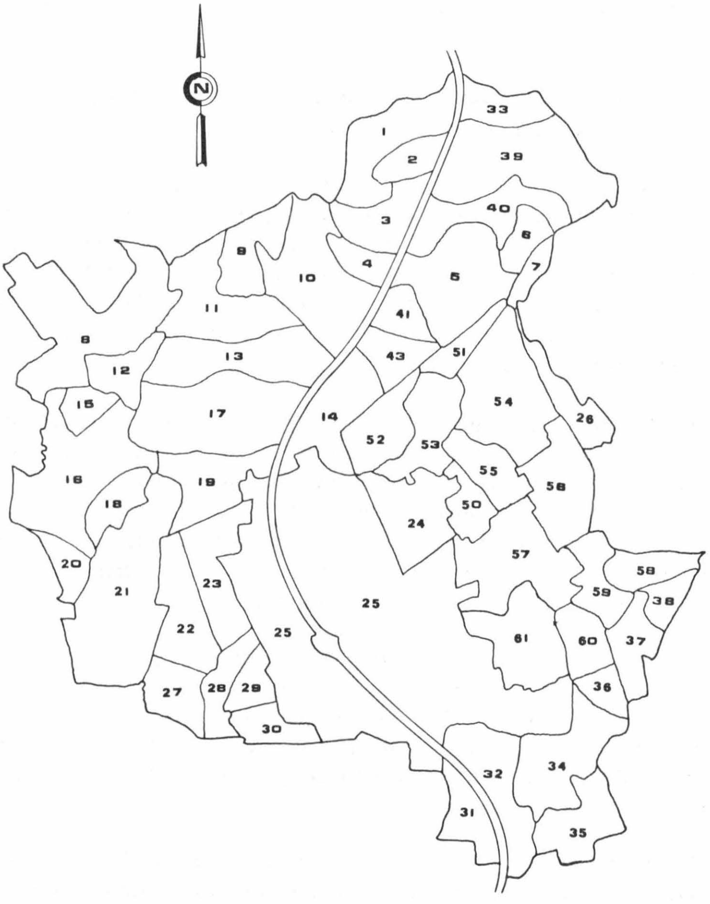


Table 11

Cost Results of TOPAZ Applications*

	Trial Description	Figure Number	Water Cost	Sewer Cost	Water & Sewer Cost	Travel Cost	Total Cost
1.	Minimization of all costs. Rough water and sewer (w&s) costs	8	206,595	187,895	394,490	827,700	6,864,700
2.	Minimization of all costs neglecting w&s Rough w&s costs	9	211,477	192,644	404,121	826,300	6,874,700
3.	Minimization of all costs neglecting sewer Rough w&s costs	10	197,038	193,926	390,964	811,900	6,873,100
4.	Minimization of all costs neglecting water. Rough w&s costs	11	206,595	187,895	394,490	827,700	6,864,700

Table 11
(Continued)

	Trial Description	Figure Number	Water Cost	Sewer Cost	Water & Sewer Cost	Travel Cost	Total Cost
5.	Minimization of all costs neglecting sewer. Model w&s costs	12	1,029,536	1,133,420	2,162,956	824,400	8,608,800
6.	Minimization of all costs neglecting water. Model w&s costs	13	1,035,579	1,132,795	2,168,374	825,200	8,661,800
7.	Minimization of all costs Model w&s costs	14	1,028,955	1,123,325	2,152,280	828,300	8,620,100
8.	Maximization of all costs Model w&s costs	15	1,110,765	1,165,955	2,276,720	968,200	9,994,400

*All costs are in dollars per year and include interest expenses.

Polytechnic Institute and State University occupies the large open space between zone 22 and the other areas where the majority of future activities have been allocated. Also, zone 22 lies directly on the path of the existing Stroubles Creek sewer trunk line and thus presently is well served for this purpose.

For future reference, it should be noted that most of A1 (single family units) have been located in zones 5, 14, and 54 to the northeast, in addition to zone 22. The main reason for these locations apparently is the availability of close-in, vacant land with most services already present. Apartments (A2) tend to be placed in zones 43 and 61 close to existing commercial areas, schools, and other apartments. Townhouses (A3) and mobile homes (A5) also tend to be placed in similar locations.

Convenience commercial uses (A6) in all allocations are lumped together in zone 61 to the southeast in the study area, across the street from a major shopping center and in the midst of many existing and future residential units. The agglomeration of these desirably small commercial units is an inadvertent and somewhat unrealistic output of the TOPAZ routine. Regional commercial uses (A7) are expected to be large in size, on the other hand, and all acreage for this activity has been placed in zone 60.

Neighborhood parks (A8) are aggregated, primarily to open spaces in zone 54 to the east (actually within the more built-up residential area of town). The larger town park (A9) invariably is placed in zone 56 on the east side of town, probably for the same reason as for neighborhood parks. Primary schools (A10) are aggregated in the eastern part of town (where the new high school currently is being constructed), while the secondary schools interestingly are located in three areas in the town among existing and proposed residential areas. We can think of no apparent reason for this reversal of the usual roles of primary and secondary schools.

Overall, the general allocation of land uses appears "reasonable" in the sense that most new activities are located close to existing ones, so that present facilities can be used and travel requirements kept low. Also, there is a fairly even distribution of schools, commercial areas, and residences over the landscape.

Three additional tests of TOPAZ were tried utilizing the rough cost figures for water and sewer services. Figure 9 shows the layout generated when both sets of costs were neglected in the determination of the minimum total cost layout. Figures 10 and 11 display the land use allocations when sewer and then water costs were neglected, respectively. With respect to the spatial arrangement of activities, the only noticeable departure from the pattern displayed in Figure 8 is that trial where the rough sewer costs were neglected; that is, water costs were emphasized (Figure 10). In that case, a sizable number of single family units (A1) and mobile homes (A5) were taken from zone 5 in the north and from zones 52 and 61 respectively and moved to the west side of the bypass (major highway through the middle of the study area and to the west of major existing development). This zone most likely was selected since there currently are many residential units being developed there and since water (but not sewer) services already are available. Thus, for example, little would have to be added to the water services for single family units in zone 17 whereas slightly more expense would occur for equivalent services in zone 5.

Considering the costs associated with the trials as presented previously in Table 11, we find that even when expenses for water and sewer costs are neglected in the allocation process, the cost for both is only $10,000 per year over that in the minimum total cost solution. Interestingly, the lowest combined water and sewer cost occurs in the trial where sewer costs were neglected. We thus can conclude as before that, in general, water and sewer costs are relatively insignificant and that if a concern still exists for these costs, greater economies can be obtained in the water system. On the other hand, there does not appear to be any economy to be gained in other services by neglecting water and sewer. Trial 2 (Table 11) shows that when they are neglected, total cost rises by $10,000 over the minimum (Trial 1)--almost the same as the increase in water plus sewer costs. Annual travel costs are reduced by only $1400.

Four trials were made utilizing the water and sewer cost models instead of the rough estimates. These trials involved:

1. Minimization neglecting sewer costs	Figure 12
2. Minimization neglecting water costs	Figure 13
3. Minimization of all costs	Figure 14
4. Maximization of all costs	Figure 18

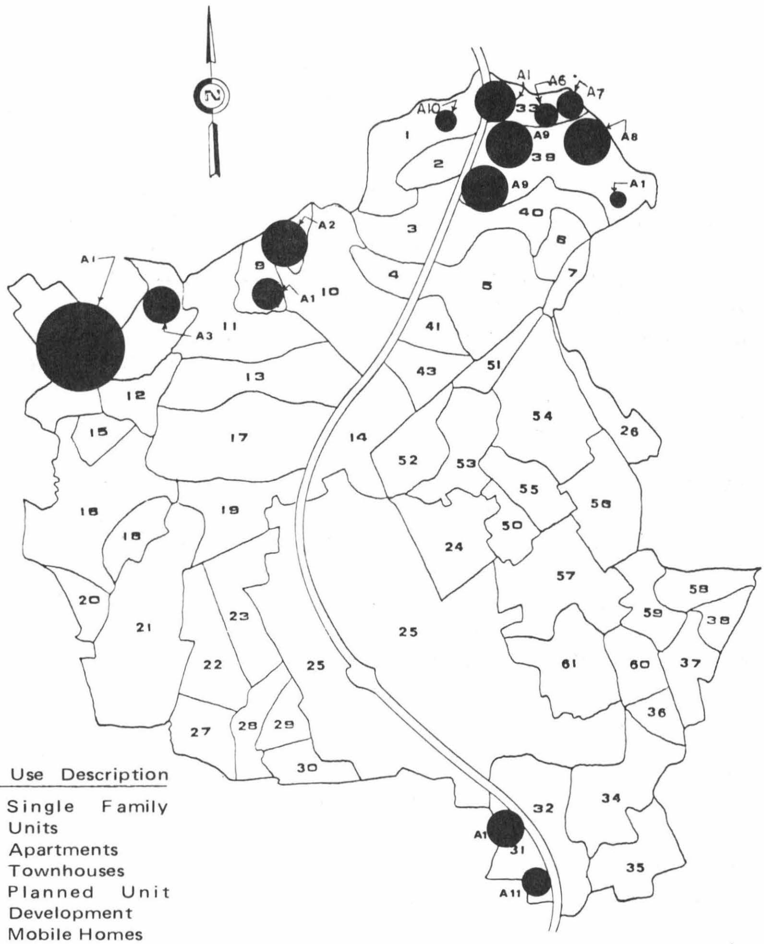
The latter trial was made to determine the worst layout of land uses (for avoidance purposes) and to provide a higher limit as a datum for judging solutions not at the minimum cost point.

Two major surprises came from these applications. First, the costs of water and sewer services were approximately five and six times, respectively, those estimated by the local developers and real estate agents. Such large discrepancies are difficult to explain but may be due to some or all of the following reasons:

(a) The rough costs might have been based on "average" conditions in the past, whereas future development would go in new areas which would be much less desirable from a service cost standpoint.

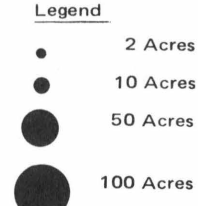
Figure 18

Spatial Layout to Maximize Total Costs



Land Use Description

A1	Single Family Units
A2	Apartments
A3	Townhouses
A4	Planned Unit Development
A5	Mobile Homes
A6	Convenience Commercial
A7	Regional Commercial
A8	Neighborhood Parks
A9	Town Parks
A10	Primary Schools
A11	Secondary Schools
A12	Public Semi Public
A13	Industry



(b) The estimators might have misunderstood our request, giving us site development costs and not taking into account trunk and major distribution lines, pumps, and so on.

(c) The estimators might not have been qualified or experienced enough to make the estimates.

(d) The estimators probably did not take enough time or make sufficient calculations (as compared to the detailed engineering work done in this study).

Whatever the reason, the conclusion certainly is that past results using the rough estimates are open to serious doubt and that much effort in future endeavors with TOPAZ must be devoted to developing more accurate models. In this study, water and sewer costs were only 6 percent of total costs using the rough estimates but were about 25 percent using the models. In addition, annual per capita costs for these two services changed from $10 to about $55 and perhaps more importantly, annual costs on a per household basis (the way in which the bills come) became about $180 per year or $15 per month. This latter figure would be larger than most current monthly bills.

The second surprise in this set of trials was that, despite the major alterations in water and sewer costs, the allocations of land uses changed comparatively little from those determined using the rough costs. It might be concluded from this either that water and sewer costs still are relatively small compared to other costs, or more likely, that those locations that would have low costs for one service also would have low costs for another. Water system costs, for example, would be lower near existing developments, as would travel and electric system costs.

Looking in more detail at the various allocations, we see in Figure 12 that when sewer costs are neglected, some single family units are placed to the north and west of the bypass in zone 4. A secondary school also is placed in that zone and a primary school is placed in zone 22. Slightly changed relative water costs in these zones probably make the resulting more desirable juxtaposition of schools and residential areas possible.

When water system costs are neglected (Figure 13), the only major change from the usual pattern involves transfer of single family units from zone 22 in the southwest to zone 54 in the east. The new activities fall almost entirely within the main drainage area of the presently developed section of town. Several allocations do fall outside of this drainage area; however, they are immediately adjacent to it and located where existing development already has occurred.

The spatial layout for minimum overall cost (Figure 14) does not present any unique patterns except for the shift of apartments closer to the center of the town.

The maximum cost allocation (Figure 18) indicates what might be expected: all activities are placed in large agglomerations in the most peripheral zones, especially to the north and west of town where rugged terrain and poor soils would make construction particularly expensive. The total cost of the maximum solution is about $1.3 million per year or 15 percent more than the minimum. Water plus sewer costs in the maximum solution are about $120,000 or only 6 percent more than in the minimum solution.*

Looking now at the costs associated with the various trials, we do not see any surprising results except perhaps that the total cost for the allocation where sewer costs are neglected is less (by $12,000) than that in which a direct attempt was made to minimize total costs. Such apparent quirks are certainly possible within the mathematics of TOPAZ since a global optimum is not guaranteed. The magnitude of the deviation is so small (less than 0.2 percent), however, as to be insignificant.

It should be noted that in the above analysis that septic tanks and wells were completely excluded from consideration. Although much of the study area is unsuited for septic tank installation, this should not be excluded from all zones. Similarly, sewage pumping stations were excluded from the analyses except where existing pumping stations already were in use. This condition places an artificial constraint on the sewer system. New development outside of any existing drainage area would utilize the existing or expanded system in another drainage area more cheaply than a completely new system in its own area. One drawback with that approach, however, would be that pumping would be encouraged and the potential for development in one drainage area would be reduced by the development in other areas.

Initial Problems in the Application

Before this study, problems were encountered in regard to the use of information generated in the original application of TOPAZ to the study area and in regard to the zonal delineation used therein. Information such as physical data on zones and zonal delineation, existing system capacities and locations, centroids of zones, locations of rock croppings or shallow bedrock, soil types found in each zone, slopes of zones, and many more, could not be found in the original study nor could it be reproduced with any certainity from the original computer program. This lack of basic information from which to build necessitated the generalizations found in the present model and analysis. Had the required information been readily available, more

*This six percent difference most likely would be less than the expected error in the water and sewer models.

sophisticated and more accurate cost models certainly could have been developed and the results derived would have been more conclusive.

A particularly difficult problem to overcome concerned the delineation of zonal boundaries found in the original analysis. The original delineation supposedly was based on several criteria that combined physical and jurisdictional constraints found in the study area. The criteria included homogeneity of slope, topography, soils, and subsurface conditions as well as man-made features such as streets, property lines, and the corporate limits of the town. Additional criteria were existing land use and the availability of existing utilities. The original study gave no indication, however, of the relative weights that were assigned to each of the criteria or of which criteria were predominant in each zone. Upon close examination it appeared that all zones within the old town limits had boundaries on streets, other rights-of-way, or property lines, with little or no regard given to the natural or topographical features of the land. Several zones in fact included portions of two or more major drainage areas. Therefore, several sewer trunk lines could be found within the same zone. The allocation of people or activities to such a zone would have different impacts depending upon where they were placed within the zone. This type of situation is counter to the purpose of zonal delineation; i.e., any activity located anywhere within a zone should be influenced, and should have the same influence, regardless of where it is placed within the zone. It could also happen that allocations in one part of a zone could have essentially the same influence as an allocation in an adjacent section of another zone. This situation is also counter to the theory of zonal delineation in that allocations in different zones should have different impacts and different establishment costs.

Recommendations

1. To obtain a more accurate water and/or sewer cost model, more emphasis must be placed on delineating basic zonal boundaries along natural drainage divides and then utilizing other criteria to refine zonal boundaries and to delineate smaller zones. In no case should portions of a single zone fall in more than one major drainage area. With such a basic delineation of zonal boundaries, many potential problems could have been eliminated in this analysis. In actual cases where development in one drainage area contributes a demand on a system in another drainage area (as in the case when sewage is pumped over drainage divides) consideration can be given to the specific case. However, when zonal delineation disregards natural drainage areas, the problem becomes compounded and a large number of cases may arise that require special study.

2. Another consideration that needs further study concerns the delineation of zones of approximately the same size. Clearly more activities

can be placed in larger zones than in smaller ones; therefore, the sensitivity of the impacts of a diversity in zonal size should be studied.

3. The sewer model should be more fully developed by incorporating Manning's equation [1, 2, and 3] into the program. At this time alternative sizes for a given slope and distance are provided by manually working the Manning equation. Presently a range of alternatives for increasing capacities for each link must be provided in advance and used as constants in the model. By incorporating Manning's equation in the cost program, a single alternative can be utilized automatically. The only input required would be the slope of the link, the demand to be placed on the link, one of several empirical roughness coefficients, depending upon pipe size and type, and the limiting velocities of the system.

4. Input data should be more carefully calculated and/or determined. In the present sewer model, the slope of a single link is assumed to be constant even though the links are several thousand feet long in some cases. This assumption neglects the effect of intermediate manholes on a given link. The result is a uniform hydraulic gradient that in actuality is not the case. Of course, one of the purposes of this model is to provide broad estimates followed by a more detailed investigation. However, the principles upon which the model is built certainly do not preclude the possibility for more detailed analyses. Such analyses must include more accurate information on the invert elevations of lines at manholes and on pipe lengths and should include links that extend only from one manhole to another with no intermediate manholes. The problems with this approach, however, are associated with the magnitude of the numbers of links involved. In the small case study area examined here there are well over 60 miles of sewer lines and over 1000 manholes.

5. The water model is quite general and only considers the cost of providing main lines in undeveloped areas plus incidental costs of secondary lines depending upon whether a zone is developed or undeveloped. This model could be made more sophisticated by incorporating a design equation to determine if the existing system will become overloaded and then to determine the cost of augmenting the flow in the existing system by building new parallel lines. The approach used in the sewer model is a little more difficult to utilize when working with water systems due to the characteristics of such systems, which include possible two-directional flows, interconnected mains, and common links between water and line "loops." The use of the Hardy Cross method [3] may be a viable application of a design equation to the water system in future analyses.

Conclusions

The purpose of the preceding experiments with TOPAZ has been primarily that of methodological development, with the hope that a larger scale application may be forthcoming. From this viewpoint, it can be concluded that it is feasible to develop useful water and sewer system models workable within the iterative optimization of TOPAZ. The models are fairly complex, containing many mathematical nonlinearities and discontinuities, yet when used with TOPAZ, they do seem to provide the proper information to allow the computation of costs for any combination of land use arrangements, and the subsequent drive towards a minimum or maximum.* The development of these models thus is a major accomplishment since previously there were no cost relationships for any general land use pattern. The results of the cost models have not been checked empirically, however, so that some doubt as to their accuracy and reliability still exists.

Another conclusion, and one that is rather forceful in this study, is that water and sewer cost models are a definite need, at least for Blacksburg. Cost estimates made by developers and real estate agents were as little as one-sixth as much as the model estimates, which we must assume are more accurate. The extra effort involved in modeling thus seems more than justified.

The results of the test in Blacksburg provide some interesting conclusions, many of which may be valid in larger, metropolitan areas. Basically these conclusions are:

1. All allocations of land use in the tests were within and/or close to existing development. This demonstrates the overwhelming economies that occur from agglomeration.

2. Costs for water and sewer services amount to about one-quarter of all costs accounted for in TOPAZ. The development of water and sewer systems thus is a sizable expense in overall development.

3. The difference between the lowest and highest costs for water and sewer services is not very great. Other costs, such as for travel, seem to vary more widely with allocation schemes.**

*Not necessarily global, however.

**Note, however, that no trials were made to minimize or maximize only water plus sewer costs.

A final conclusion concerns the delineation of zones and data needed for this purpose. Since the location and cost of water and sewer distribution systems is so heavily dependent upon topography and soils, good cost models can be developed only if the modeler plays a strong role in zonal delineation. Otherwise, a zone may be chosen that covers two or more watersheds (that involves both permeable and nonpermeable soils, etc.). Such selections would create a high degree of initial variability in the models.

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Part III

THE SEARCH FOR BENEFIT CRITERIA AND OPTIMAL CITY SCALE

Introduction

This part of the report examines two areas of fundamental concern to the user of TOPAZ. The first section is devoted to a search for benefit criteria which might be used to supplement the technique's cost criteria, while the second section attempts to identify the causes of high physical cost in the living environment and an optimum urban scale for physical cost.

To clarify the problem of including additional benefits in the technique, the first section begins with a discussion of TOPAZ's cost and benefit criteria and theoretical foundation in economic location theory. This is followed by an assessment of consumer's surplus as a measure of relative worth, other contributions from welfare economics, and the use of net regional product as a benefit.

Apart from having to attempt to balance benefits against costs, the TOPAZ user must have an independent understanding of the relationships in the urban setting which the technique underplays or ignores. For instance, to give greater meaning to the technique's results, the user must consider the questions of optimal density and population size, for the technique only distributes land uses within the context of given growth and density inputs. Moreover, the user must consider the operating costs which result after development is in place. The technique at present considers only one operating cost (for travel) and otherwise bases its least-cost solution on the capital costs of growth.*

The second section of this part examines total capital and physical operating costs of cities from the perspective of urban scale, considering both government and private expenditures. Urban scale in this sense refers to that combination of population size and density and settlement spacing which characterizes an area. Scale will be analyzed in terms of economies which might exist in the provision of public and private services and facilities, and the variations in cost which may result from different densities and sizes. In essence, the second section attempts to identify an optimally scaled city for physical costs, and relate its implications to the use of TOPAZ.

*Other operating costs, such as water supply and sewage disposal, could be added, if desired.

THE SEARCH FOR BENEFIT CRITERIA

Present Criteria in TOPAZ

The present criteria in TOPAZ include establishment costs (i.e., on-site construction costs), the costs of installing water, sewer, local streets, electric utilities, and travel costs. On the benefit side, the technique treats land value as a factor which reduces the overall cost of placing an activity at a location because a site's income earning ability or user potential is directly reflected by its value. [1]

Land value in each zone is predicted through a regression equation based on the proximity of the zone to various activities such as schools, shops, and the central business district.* Establishment and installation costs are determined for each potential future activity in each zone and used as inputs to the technique. In turn, land value and transport costs (determined with a gravity model) vary according to the potential allocations of future activities explored by TOPAZ's mathematical program.

The last two criteria of land value and transport cost directly tie future locations to existing activities. As distance from the center of a city and its outlying nodal points increases, land values decrease. Moreover, as trip distances increase, transportation cost increases. Here, the technique incorporates the concept developed by Haig and Wingo of the "comparability" between rent and transport cost. In general, these costs can be said to vary inversely. [2] Also linking future allocations of land uses to existing development are the greater costs of providing sewer, water, and electric facilities as distance from existing lines increases. Each of these criteria reflects agglomeration economies.

Establishment cost, on the other hand, can be thought of as a neutral factor unaffected by accessibility. It varies with surface slope, bedrock depth, the weight carrying capabilities of the land, etc. For instance, the more gentle the slope, the lower the cost of construction, while shallow bedrock usually means greater costs for the on-site installation of sewer and water lines. Relative to the other factors, establishment costs are highly significant. In the case of Blacksburg, for example, they are often more than half the total because of the relative insignificance of transportation costs in such a small community.

The interrelationships found in the technique and its criteria largely reflect the influence of economic location theory. This is evident, for instance, when

*These regression equations were developed after the analysis done for the example presented in Part I. In that example, it was assumed that land values were constant for each activity in each zone.

we observe that an optimal location for a firm is based on such considerations as average production costs, revenue potential, transport costs, and economies of agglomeration. [3] Likewise, TOPAZ attempts to relate production costs (at least in terms of establishment cost), income earning ability (through land value), transport costs and economies of agglomeration to all activities which may develop in an area in searching for an optimal distribution.

The shortcoming of TOPAZ is unlike a general economic theory of location, the optimum is not that point in space which maximizes the difference between benefits (e.g., gross revenues) and costs (e.g., total production cost). Because of difficulties in establishing and quantifying many benefits, the use of benefits in TOPAZ contrasts sharply with the use of neat measures of profit in such theories. The result is that TOPAZ has been heavily weighted on the side of minimizing the cost of development.

The problem of including benefits in the technique is illustrated by land value. As previously mentioned, its benefit quality is derived from its relationship to proximity and therefore to user or revenue potential. Since land values are low (compared to those in metropolitan areas) and vary little in Blacksburg, the use of land value as a measure of the benefits of proximity does not create difficulties here. In the case of the least-cost development scheme, for instance, it reduces total cost by less than 5 percent.

As later analysis will show, the use of land value as a benefit may create problems through its relationship to density. High densities in large cities in particular may lead to greater total capital and operating expenditures. Moreover, the benefits of proximity are inherently included in travel cost. To illustrate, those sites which maximize user potential for schools are those which minimize travel cost to and from school. Thus, areas with greater travel distances than Blacksburg (such as Melbourne) may not need this supplementary measure of proximity. The potential problem with land value as a measure of benefit will be clarified by the analysis in the second section of this part.

In short, while the criteria in TOPAZ for identifying an optimal distribution are based on many of the factors considered in location theory, TOPAZ suffers from a lack of quantitative benefit criteria needed for comparison against costs. [4] In an attempt to establish an adequate measure of the net benefit of each development scheme, the next few paragraphs examine concepts developed in cost-benefit analysis, welfare economics, and regional economics. Louks [5] has identified eleven goals and related criteria in the economics and water resources literature (see Table 12). Only selected ones of these criteria will be discussed here.

Table 12

Some Public Policy Goals and Possible
Units of Measurement

Goal		Examples of Units of Measurement
1.	National Economic Growth	Discounted GNP, GDP, or Terminal GNP, \$; increase in total income, \$; terminal capital stocks, \$.
2.	Aggregate Consumption	Discounted consumption or utility of consumption, \$. (Standard of Living)
3.	Income Distribution	Total weighted sum of logarithms of consumption of each income class, Gini coefficient, Theil coefficient, variance, coefficient of variation, relative mean deviation.
4.	Price Stability	Change in unit market or social price for various goods and services, \$.
5.	Self Reliance	Balance of payments or trade deficit, \$; or employment of foreign labor, number or percent; discounted foreign exchange surplus, \$; total imports, \$.
6.	Educational Opportunity	School enrollments by grade, number or percent.
7.	Productive Capacity	Investments, \$.
8.	Employment Level	Total unemployment or underemployment weighted by income groups, number or percent.
9.	Regional Development	Gross regional product or production, \$; change in relative rates of aggregate or per capita growth in region, number or percent.

Table 12
(Continued)

10.	Environmental Quality	Mass and energy residuals discharged in air, water, and land; weight, volume, concentration, temperature, decibel level.
11.	Social Mobility	Sum of weighted changes in employment by occupation, number or percent.

Consumers' Surplus

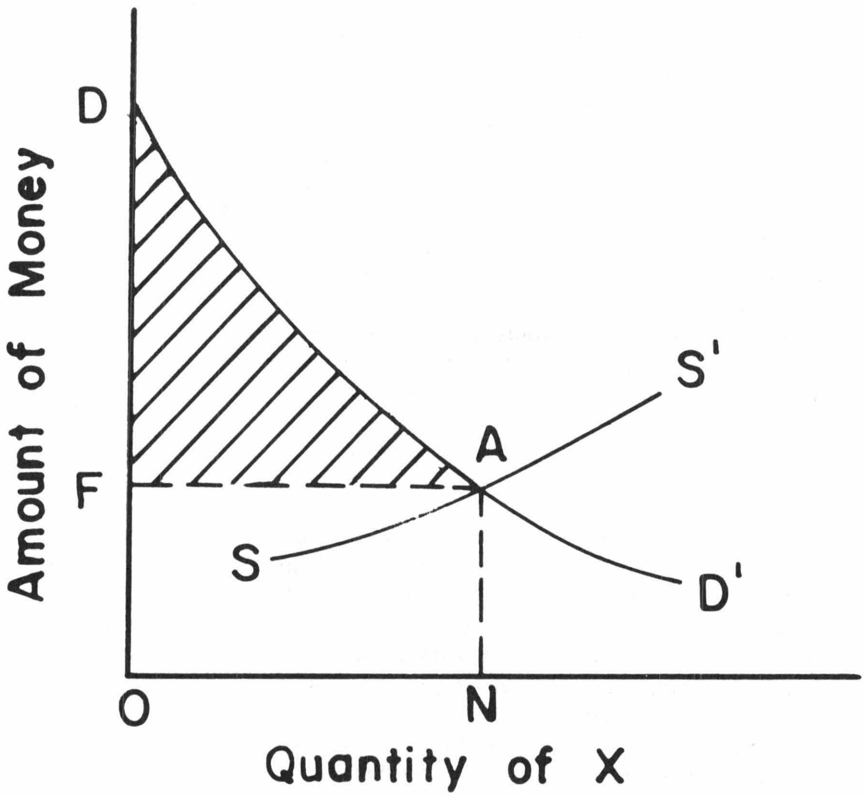
The first concept investigated was consumers' surplus: the difference between what is paid for a commodity and what consumers would be willing to pay. Interest in using consumers' surplus as a measure of benefit was sparked by a survey of residential preferences conducted in Greensboro, North Carolina. Residents were asked to rank the city and neighborhood characteristics that were most important to them. The survey findings included the following preferences for city and neighborhood amenities: spaciousness (which was first), quiet, friendliness of the neighbors, close proximity to grocery and drug stores, well paved streets, tree lined streets, sewer and water and electric services, etc. [6] Given the types and amounts of amenities in each zone, it was felt that demand curves indicating residential preferences could be traced, approximating willingness to pay for each of these. The concept of consumers' surplus is illustrated in the graph in Figure 19 of the demand and supply curves for a commodity X. [7] Given the demand curve intersecting the supply curve where marginal cost equals zero, at point A, the shaded area DAF represents consumers' surplus. In this case, OFAN is the total amount paid, while ODAN would represent the total had it somehow been possible to obtain from consumers the maximum amount each would have paid for every successive unit bought, rather than go without the product. The difference between what was paid and what consumers would have been willing to pay is the consumers' surplus or net benefit derived from the price OF. [8]

The concept of consumers' surplus originated with Jules Dupuit's paper "On the Measurement of the Utility of Public Works" in 1844, [9] and was eventually used in cost-benefit analysis in the 1950's. It continues to be used through extension and modification by economists' attempting to measure the benefits of such public works projects as highways, bridges, airports, and dams. [10] Economist David M. Winch [11], for instance, uses a variation of consumers' surplus in transportation planning. In the examples he provides, streams of benefits are measured over the life of a facility to derive the "total net benefit" of that facility. By deriving the benefits of various alternatives, Winch also uses the concept comparatively. For instance, the benefits of an existing road are contrasted to the potential benefits of an improvement or a new road to determine the best alternative. Others, such as Dasgupta and Pearce [12] use a modified consumers' surplus approach in cost-benefit analysis.

To place trust in this measure, however, requires making most, if not all, of the following assumptions: (1) the existence of rational, economic men; (2) a measure of cardinal utility in each person's mind; (3) an ability to measure this utility either in the market place or through some reliable predictive model; (4) an ability to add these utilities and treat them collectively; (5) one nonsubstitutable product; (6) perfect competition; and (7) a marginal utility of money that remains constant (which further depends on a constant real personal income). [13]

Figure 19

Illustration of Consumers' Surplus



As its assumptions indicate, the consumers' surplus approach raises difficult questions. In defense of its use in cost-benefit analysis it should be noted that it is applied only under very special circumstances, usually for one long term project which can justifiably be considered a nonrecurring expense. The product in these cases is nonsubstitutable as required, in that it is not available in the market place, and only several consumers collectively can justify construction. Also, consumers' surplus in this case is made more acceptable by the possibility of approximating a demand curve. For instance, several empirical observations of the demand for highway facilities have been made over the last two decades. [14]

However, to extend the use of consumers' surplus beyond these special cases, is inappropriate. As Winch, and Dasgupta and Pearce [15] have mentioned, even for one item, the upper end of the demand is highly conjectural. Others, such as I. M. D. Little, [16] are far more critical. He concludes:

> "consumers' surplus is a totally useless theoretical toy . . . . the plain truth is that it does not yield us any criterion at all--or if it can be said to yield a criterion, then it is open to anyone's interpretation within very wide limits" [16]

With respect to TOPAZ, for instance, more ambitious use of the concept would require that it apply not to one item but to a package of abstract amenities, including topographic characteristics, proximity, and spaciousness. In the end, we would be left with a demand curve for each zone based on a dubious list of preferences for several interrelated and conflicting amenities. The curve would appear to reflect a combination of people's preferences and thus what individuals would be willing to pay for those amenities.

In terms of the assumptions listed above, making this leap requires the existence of a cardinal measure of utility. Cardinal utility, in turn, depends on the existence of economic men--people who attempt to maximize utility by ranking all relevant alternative combinations of goods and services according to their mathematical expectations of utility, and thus according to the prices they are willing to pay. Not only does this assume that individuals can rank preferences such as saying they prefer A to B and B to C (ordinal utility), but that they can say they prefer A to B by so much, and that they prefer A to B by so much more than they prefer B to C, etc. (cardinal utility). [17]

Because of these questionable characteristics, cardinal utility is rejected by most welfare economists as far too restrictive. [18] Because of this and its other assumptions, consumers' surplus cannot be used for our purposes.

General Welfare Theory and Welfare Economics

The search for an approach to measuring benefits leads us further into welfare theory and the general theories of such familiar names as Pareto and Arrow. In essence, their theories provide two basic criteria for evaluating the impacts of possible actions we might take. These criteria would be useful only if we could arrive at some degree of concensus on what welfare is. The first is that our decision must be based on whether or not a change (or no change) will make at least one person better off without making another worse off. The second is that if a change creates losers, the cost that they incur must be more than balanced (or more restrictively, compensated) by the gains of the winners. If these conditions cannot be met, then a change will not move us in the direction of greater general welfare. [19]

In relation to TOPAZ, these criteria stress the importance of carefully questioning apparent benefits and costs and properly identifying and defining real ones. These general theories do not, however, point to an approach which might be taken to include benefits in the model.

Turning to other, more specific contributions from the field of welfare economics, again we find that they apply only on a level largely above and apart from our particular concern with the ordering of land uses in an urban community. On the national scale, welfare economics makes contributions by its focus on such subjects as the distribution of income, the question of present versus future income, fiscal and monetary stabilization policies, externalities, etc. [20] Its primary concern, however, even when applied to a regional or urban scale, is with performance. It only touches on questions of location indirectly.

Net Regional Product

On the more selfish level of intercommunity competition, we hoped to borrow from the concept of net regional product in attempting to measure benefits. Net regional product essentially refers to a community's balance of trade with the rest of the world: its exports minus its imports. [21] The less spent on materials and labor that come from outside the community on the five costs used in TOPAZ, for instance, the greater the net regional product. In the case of Blacksburg, an unofficial telephone survey of contractors indicated that roughly 85 percent of the money spent for on-site construction, transportation and the installation of sewer, electric, and water lines, leaves the area.

On the basis of this figure, by comparing the total costs of alternative development schemes, we can partly identify the effect of each development pattern on Blacksburg's net regional product. Note that part of any savings that remained in Blacksburg would be used to purchase other imports. While this measure would be of importance in analyzing the Blacksburg economy, it is of little use for our purposes simply because it does not help distinguish the variations in benefits associated with each scheme. It merely suggests that the difference in savings between each scheme is proportional to the difference in cost, something implicitly assumed.

Conclusion

In the final analysis, incorporating additional benefit criteria into the technique is hampered by our inability to reliably measure and quantify them. Thus, we are faced with the necessity of attempting to add to the findings of the technique by qualitatively estimating the benefits associated with each scheme and weighing them against cost. One possible way to supplement the analysis is suggested by the survey of neighborhood preferences of the residents of Greensboro, North Carolina. The findings of a survey could be combined with the technique's results either by weighing people's preferences in the evaluation of alternatives or by introducing them into the technique as planning standards (e.g., by lowering the inputs of per acre densities). Even without a survey, if we can either draw on a list of community goals and objectives or test people's reaction to each development scheme, we might acquire a reasonable degree of perspective on the relative worth of each scheme. For example, some inexpensive distributions of land use might be deemed either socially unacceptable or inimical to community goals. In short, testing development schemes against people's reactions or evaluating different schemes on the basis of qualitative preferences (i.e., ordinal utility) is far more desirable than introductory nebulous indifference curves into the technique.

THE SEARCH FOR OPTIMAL CITY SCALE

To overcome the technique's limited focus, an examination will be made of the variations in physical costs attributable to differences in urban scale. Physical cost in this case will refer broadly to all costs related to the normal provision of government services and facilities and private facilities in the living environment. As such, physical costs are to be distinguished from the "social cost" associated with welfare and crime.

In this investigation of physical costs attempts will be made to determine the causes of high cost, economies of scale, and an optimum or threshold of development. Because "conditions of great complexity" prevail in any attempt to identify an optimum, many apparent and real contradictions will appear. Any attempt to submerge them would be both futile and self-defeating.

The search for optimum scale will be applied only to physical costs, as distinct from other attempts to identify an optimum on the basis of such factors as economic performance, the scope of public and private services, and opportunities for social interaction. [22] These three factors are excluded partly because of difficulties in defining and measuring them. More importantly, they may not be so dependent on different degrees of urban scale as on other qualities of their environment. Thus, defining an optimum on the basis of these factors becomes highly speculative. In contrast, costs are relatively concrete and well documented and as we shall see, inextricably tied to differences in urban scale.

To address the questions of cost and optimality, this part of the report is divided into two basic sections corresponding to the information available about changes in cost related to changes in urban scale. The first section will draw from the literature on government expenditures, beginning with an assessment of the effect of (1) population density and settlement spacing (i.e., housing density), and (2) population size on increased public costs. This, in turn, is followed by an attempt to identify an optimum on the basis of public costs. The second section is focused on P. A. Stone's detailed analysis of private as well as public costs which result from the development and operation of structures and facilities in the city. Given this more complete information, an attempt is made to identify an optimum on the basis of both public and private costs. Finally, an evaluation of the certainty we can attach to an identification of an optimum and a discussion of its implications for developmental planning will be made.

The Causes of High Public Spending

A great deal of research has been done to identify the causes of increased government expenditures. While much of the work is focused on operating expenditures, capital expenditures are occasionally included. All these efforts have had to wrestle with data problems. Complicating any analysis of the costs of local government services and facilities are differences in the levels of (1) state and federal aid, (2) incomes and their distribution, (3) the quality and number of services, (4) purchasing power of the dollar in different areas, (5) types and potentials of revenue sources, (6) general as contrasted to earmarked funds, and (7) overlapping governmental jurisdictions. [23]

Several strategies can be used to mitigate these potential pitfalls. For instance, the use of large samples helps minimize inconsistencies, in that errors of overestimation tend to be offset by errors of underestimation. Another method employs analysis of geographic areas on common bases, such as inclusion of only those counties with a density greater than 100 persons per square mile, and an aggregation of the expenditures of all special districts, townships, and municipalities within each county in one set of figures. [24] Probably the most common method is the exclusion of incomplete or incomparable data, particularly for education operating expenditures.

Different techniques of data analysis and differences in the variables analyzed present further problems of interpretation. A benefit from these differences, however, is that the existence of a factor that significantly influences costs should be drawn out in most of the studies under the guise of several related explanatory variables.

To test and compare the results of these studies, it is hypothesized that density, far more than any other factor, significantly contributes to high levels of government expenditures. Density is chosen for several reasons. First, it is reflected in two aspects which define urban scale: population density and settlement spacing (e.g., housing density). Secondly, population density adds perspective to comparisons of areas on the basis of population size by placing size in a context of distinct spatial dimensions. Finally, any influence of density on specific categories of expenditures or total expenditures will have significant implications for an identification and understanding of an optimally scaled city.

The Density Hypothesis and General Studies of Government Expenditures

The analysis begins with an examination of education, the largest local government expenditure category. [25] Because school system expenditures are often handled directly by school districts, total per capita expenditures for this service within a city's boundaries are often excluded or partially omitted from city budgets. Thus, analysis of this expenditure is very limited. The most complete treatment of education for purposes of analyzing density and urban scale is presented here. Based on 1957 Census of Governments' data and 1960 populations, Campbell and Sacks determined per capita government expenditures in the 36 largest S.M.S.A.'s for which data were available. Relevant parts of their findings are shown in Table 13.

For education, the most revealing aspect is that per capita operating expenditures in the suburbs are almost identical to those in the cities if the difference in state and federal aid to education (all for operating costs) is considered. Without this aid, for instance, the suburbs spent $49.41 dollars per capita on their school systems (calculated by subtracting Education Aid from current Education Expenditure). Thus, residents of these cities paid approximately the same per capita for education operating expenditures as their suburban counterparts, despite their lower per capita incomes, the greater requirements and hence drain from noneducation expenditures, and the slightly smaller portion of the intergovernmental aid ($34.72 as opposed to $40.26). Without the greater aid to the suburbs, other data presented by Campbell and Sacks show that direct per pupil expenditures were actually greater in the cities than in the suburbs. [26]

Despite these high city government expenditures, we cannot conclude that density exerts a high cost pressure on education expenditures, because this sample is small and we do not know what differences in quality or density might exist. Rather than density, intergovernmental aid for education accounts for the identifiable variation in expenditures for education.

If we reduce our concern to scale economies associated with enrollment in individual schools, data analyzed by Isard for Florida, Indiana, Idaho, and Pennsylvania indicate that per pupil operating costs declined for enrollments in secondary schools up to a size of 1000 students, and increased slightly for higher enrollments. For elementary schools, on the other hand, a threshold was reached at an approximate size of 500 students. [27] Thus, while economies of scale were found to exist, they appear to have been used up for schools of a moderate size. The effects of density, however, are obscured by the possibility of finding schools of small and moderate sizes even in densely settled areas. While this is not what we would logically expect, a lack of adequate supporting data precludes our tying density to increased spending for schools.

In terms of non-education expenditures in Table 13, the difference between cities and suburbs may reflect a substantial influence of density on costs. The biggest discrepancy in these costs is found in the subcategory "all other." This represents the common government functions of general control, police, fire, sanitation, sewage, and water operating expenses. [28]

A review of efforts made to explain these differences in cost begins on a general level with Schmandt and Stephens' analysis of total government expenditures for all counties or their equivalents in the United States. Like Campbell and Sacks they used 1957 Census of Governments' figures with 1960 census data for per capita comparisons. They found size to be the primary determinant of high per capita capital and operating expenditures and did not analyze density. Their findings reveal the cost curves shown in Figure 20.

Table 13

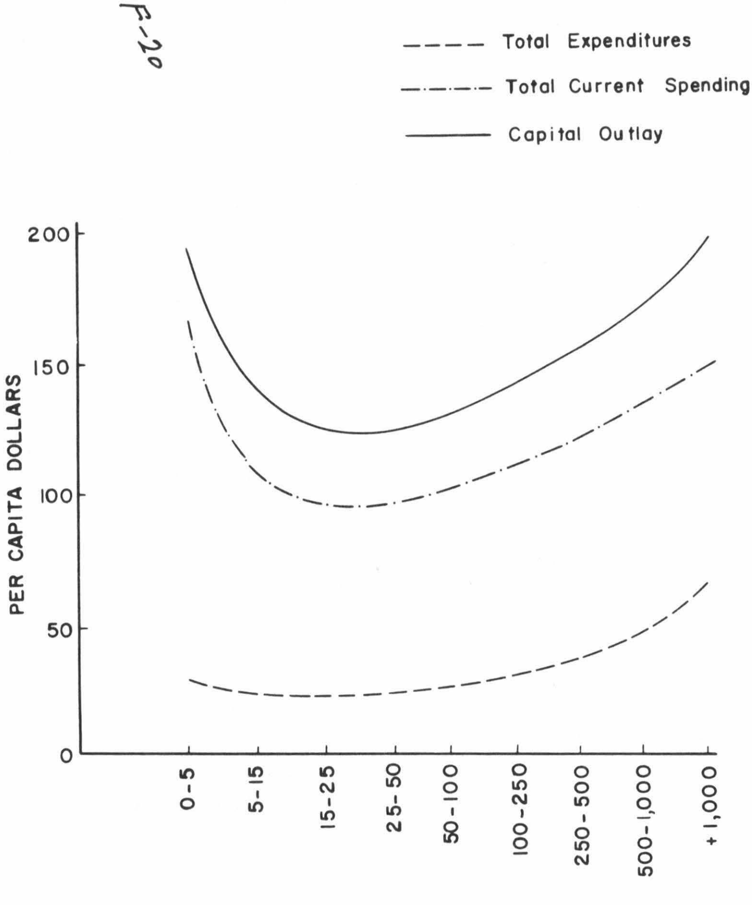
Per Capita Government Expenditures in Thirty-Six S.M.S.A.'s by Central City and Suburbs, 1957

Per Capita	Central City	Suburbs	Differences
Total General Expenditure	$ 185.49	$ 159.83	$ 25.66
Education Expenditure	58.02	85.84	- 27.82
Current	49.16	61.72	- 12.56
Capital	8.86	24.12	- 15.26
Noneducation Expenditure	127.48	73.95	53.53
Total Highways	16.55	14.41	2.14
Health and Hospita	14.84	7.09	7.55
Public Welfare	10.22	8.34	1.88
All Other	85.70	43.80	41.90
Total Aid	34.65	39.72	- 5.07
Education Aid	16.12	28.43	- 12.31
Noneducation Aid	18.60	11.83	6.77
Exhibit			
Per Capita Income	1,998.86	2,280.50	-281.64

Source: Alan K. Campbell and Seymour Sacks, Metropolitan America, (New York: The Free Press, 1967), p. 118.

Figure 20

Mean Per Capita Expenditures of County Area Aggregates by Population Size, 1957



Schmandt and Stephens also found that per capita indebtedness was more than three times greater for areas of over one million inhabitants compared to those in the 5000 to 14,900 size class, by $351 to $109. [29] While size here should not simply be equated with density, the relationship is highly significant. Note that Bahl found a correlation between population size and population density of 0.514. [30] Other evidence of a "U"-shaped capital cost curve shows up in the work of Svimez of Italy in Table 14.

Additional and still more convincing evidence is found in the Bureau of the Census reports of per capita revenues and expenditures in all U.S. cities for fiscal years 1969 and 1971. Because of the similar findings in these reports and the questionable use of 1960 population data for fiscal year 1969, only the 1971 data are reproduced here.

As illustrated in the table, many items register increases in cost as population rises in an almost straight progression. With the exception of classes four and five, when revenues, adjusted general expenditures, and indebtedness are combined, they all show increases as size increases.

Statistical Analyses of Density

Shifting from an observation of costs associated with population size to studies of the effects of density on government costs, more definitive conclusions can be drawn. The Advisory Commission on Intergovernmental Relations concludes that population concentration increases the need for or scope of costly functions such as police and fire protection, sanitation, recreation and parks. [31] Robert F. Adams' extensive analysis, based on 1957 data of 478 county areas including their respective cities in 45 states, substantiates ACIR's statement. To limit the analysis and reduce the possibility of interactions between explanatory variables, Adams chose only those counties with population densities exceeding 100 people per square mile.* Analyzing seven cost categories (excluding education), Adams found that for police, fire, sanitation, and recreation expenditures, density was the only explanatory variable significantly above the mean per capita expenditure for each service. While density loaded similarly on sewage (non capital) costs the percent of variation explained by all the variables was less significant with a total R^2 of 0.281, and 0.215 for density. For general control and street maintenance costs, density explained none of the variation. [32]

*Analysis of density in terms of either population or housing in this and other studies rests on the crude measure provided by total county or city land area, rather than on more precise measures based on the urbanized area of cities and counties. This suggests that much of the true effects of density on variations in cost is hidden from statistical analysis.

Table 14

Relation of Infrastructure Costs to Settlement
Size in Italy

Settlement Size	Infrastructure Costs Per Head of Population
(Number of Persons)	Percentage
Up to 5,000	128
5,000-20,000	102
20,000-50,000	100
50,000-100,000	105
100,000-250,000	111
250,000-600,000	120
600,000 and above	140

Source: Svimez (Rome 'Ricerca sui coste d'insediamento' quoted in Regional Policy in the European Free Trade Area, EFTA, 1968, Chapter 3; extracted from P. A. Stone, "Economics of the Form and Organization of the City," Urban Studies, Vol. 9, No. 3 (October 1972), p. 332.

To provide an indication of the impact of population density on expenditures found in this study, a portion of the findings are shown in Table 15 for per capita police expenditures.

These findings are also similar to those of Bahl, who analyzed 198 S.M.S.A.'s from 1962 census of government data. Like Adams, he excluded education expenditures. For this year, in addition to its association with greater costs for police, fire, and sanitation, population density was the most significant factor influencing general control expenditures, where r = 0.4151, while it was insignificant in explaining recreation expenditures. The only factor significantly affecting the recreational expenditure was dwelling units per square mile (r = 0.2746). [33] Bahl also tested an earlier hypothesis made by Hawley (76 cities), [34] and later verified by Brazer (462 cities). [35] Hawley hypothesized and found that as the size of the suburban population increased relative to the central city population, the costs of city government rose for both operating and capital expenditures. Both Bahl's and Brazer's findings were in agreement, though Brazer only analyzed operating expenditures.

Aside from population density, where r = 0.441 for total expenditures and 0.524 for operating expenses, and the size of the urban fringe population, where r = 0.390 for total expenditures, Bahl found that the ratio of city employment to city population was significant in explaining high total expenditures, where r = 0.355. [36] In addition to these variables, two other factors which might be logically associated with high government costs have been tested: median family income and rate of population growth.

In the studies of Hawley and Bahl, the rate of population growth was not found to have any effect on variations in costs. [37] Bahl also reports that in at least four other studies (which include those of Adams and Brazer), the functional relationship between population growth and per capita expenditures was found to be inverse. [38] In other words, the faster the rate of growth, the lower the per capita expenditures. This logically follows if growth results in increased use of existing services and facilities and if governments are somewhat slow in their initial response to the needs of newcomers.

The effect of income is also somewhat surprising. In the studies of operating expenditures conducted by Adams and Bahl, median family income was found to be positively related to cost in all categories, but almost uniformly below the level of statistical significance (i.e., 0.05). This was also true of three other studies testing this variable, except Brazer's in which there was significance. [39] These findings are better understood in light of density's affect on cost. Attributing the cause of the variation in costs to density rather than to income, means, in effect, that even if high family incomes generally result in greater expenditures, density accounts for higher levels of expenditure among those areas with high family incomes. However, that income may not generally result in greater expenditures. The figures from Table 13 reveal

Table 15

The Effect of Density on Per Capita Police Expenditures

Density (Persons/sq. mile)	Number of Cases	Unadjusted Deviations*	Adjusted Deviations**
100-266	277	\$-1.307	\$-0.807
267-432	59	-0.141	-0.532
433-598	32	0.691	-0.105
599-930	27	1.081	0.191
931-1760	36	2.685	1.378
1761-3420	18	1.947	1.964
3421-5080	15	5.006	4.697
5081 and over	14	8.185	6.492

*Deviations from a grand mean of \$5.862 per capita

**Deviations are adjusted to account for variations in regional expenditure levels

Source: Robert F. Adams, "On the Variation in the Consumption in Public Services," in Essays in State and Local Finance, ed. by Harvey F. Brazer, (Ann Arbor: University of Michigan, 1967), p. 18.

that on an average for 36 S.M.S.A.'s in 1957, central cities spent considerably more than their suburban counterparts, despite having considerably less per capita income or intergovernmental aid. Thus, while government spending levels may vary in some cases with incomes, income does not appear to have any explanatory significance.

By an analysis of city government expenditures, exclusive of fringe areas in each S.M.S.A., Bahl noted a factor which further confirms these observations. Using stepwise regressions on the dependent variables "total expenditures" and "operating expenditures" and seventeen independent variables, Bahl obtained R^2 's of 0.4084 and 0.4562, respectively. Only the housing density variable accounted for much of the positive variation, with R^2's of 0.2137 and 0.2891, respectively. Housing density was followed by "intergovernmental revenue as a percentage of total revenue" with R^2's below 0.0550. Population density was insignificant in both tests. [40]

In analyzing the parts of S.M.S.A.'s, Hawley found that for total expenditures, housing density in the suburbs ($r = 0.57$) and in the cities ($r = 0.55$) was slightly more significant than population density in either one. He found housing density in each case to be even more highly related to operating expenditures than total expenditures. [41] The implications between Bahl's analysis and Hawley's findings are diminished by Hawley's small sample and analysis of 1940 data and the possible variations between population and housing density in both studies. Nonetheless, it is apparent that density, whether defined by homes, people, or both, results in increased capital and operating expenditures, exerting its strongest effect on operating costs.

Also adding support to the density hypothesis is the evidence of a central city exploitation thesis. For 1962, Bahl concurs with the analysis of Hawley and Brazer for the two previous decades by showing that besides density, the size of the population and the number of workers commuting to the central city (i.e., the ratio of city employment to city population) were influential in generating high costs. It would appear then that the greater the surrounding population, the greater the drain by that population on central city services.

This explanation is weakened, however, by the possibility that what is being measured includes the cost of greater density. It would seem that the smaller the center's population in relation to the total population, the more heavily developed the area within the city's boundaries would be. Hence, a large suburban population, in terms of its positive loading on costs, may not only reflect a drain on the city's services but also the higher cost of density.

Arguments Against the Density Hypothesis

Thus, density shows up significantly in all tests and appears to create problems of multicolinearity for other factors being tested against cost. As we have noted, the significance of density cannot be readily explained by higher incomes or high growth rates. Three other related factors which have not been tested may appear on their face to be pursuasive arguments against the density hypothesis. These include the idea that dense areas receive a greater number and scope of services than other areas, the possibility of higher quality services and high social costs. [42]

The argument which stresses that more services are delivered to people in dense areas is valid, but whether or not it contradicts the density hypothesis depends on the benefits derived from these additional services. As Isard observes, dense settlement results in more intensive use of natural resources, and consequently in an increased need for services to provide the same quality environment. [43] At a basic level, for example, we find that in areas with sufficient soil permeability sewage can be treated with septic tanks for two dwelling units per acre, but not for three. In short, depending on the intensity of use, a limited number of functions can be borne directly by the individual or by his immediate environment.

The related argument of higher quality may have validity in some cases, but generally the evidence points to the conclusion that it is lower in areas of greater density. We can point to the greater use and number of services which reduce the individual's disposable income. Additionally, the finding that density explains the variation in government costs is a strong indication that crowding makes the provision of public services more difficult. If this is true, we would expect people to pay more to maintain the same quality of service. On the other hand, if more were not spent, we would expect this greater exploitation of services to result in a sacrifice of quality. [44]

Both higher expenditures for the same quality of services and a greater need for services are better appreciated when we examine "social costs" and their relation to density. The social cost (e.g., for what ACIR terms "high cost citizens" such as the poor and disadvantaged, criminals, delinquents, etc.) [45] reflected in central city budgets are hard to identify, but it is well known that they are greater than in suburban and non-metropolitan areas. In Table 13 expenditure categories that we might normally associate with social costs such as welfare, health and hospitals, and police are considerably higher in the large central cities. The crucial question for purposes of assessing normal physical costs is: How significant is the difference in social cost between areas, and what is its relation to density?

The impact of social cost on total cost, is probably best gauged by city welfare expenditures. Note that these expenses will generally reflect the cost of administration, or city funded facilities run for the poor such as, day care centers, while they would not reflect direct state and federal payments to welfare recipients. According to Table 16, this social cost does not exceed roughly 2 percent of total general expenditures for cities with less than 500,000 persons. This implies that with the particular exception of the six

Table 16

Per Capita Amounts of Selected City Finance Items by Population-Size Groups

Fiscal Year 1971

Item	All Municipalities	Population Size* 1,000,000 or more (7)	500,000 to 999,999 (6)	300,000 to 499,999 (5)	200,000 to 299,999 (4)	100,000 to 199,999 (3)	50,000 to 99,999 (2)	Less than 50,000 (1)
General revenue, total	$231.62	$544.60	$341.81	$247.04	$246.12	$224.40	$181.68	$119.39
Intergovernmental revenue	73.46	227.50	112.98	69.47	73.23	62.60	42.06	26.99
General revenue from own sources	158.16	317.09	228.83	177.57	172.89	161.80	139.62	92.41
General expenditures, total**	242.02	568.58	350.28	270.73	263.20	234.50	189.10	124.50
Education	39.71	107.57	50.85	57.33	44.93	48.66	34.98	12.48
Highways	20.18	19.64	25.20	20.80	26.77	20.53	20.08	18.61
Public Welfare	20.36	108.79	30.66	5.58	6.67	4.77	2.53	0.99
Hospitals	13.48	47.17	22.25	6.97	4.91†	7.20	5.56	5.73
Health	4.12	14.27	9.62	3.94	3.41	2.83	1.53	0.69
Police protection	26.29	55.40	40.75	27.69	26.26	24.33	20.94	15.44
Fire Protection	15.12	23.12	21.27	20.15	19.84	19.84	17.01	8.71
Sewerage	13.39	13.99	18.10	17.77	16.04	14.63	11.65	11.55
Sanitation other than sewerage	9.42	18.77	12.45	9.93	13.25	8.79	7.99	5.94
Parks and recreation	10.90	13.48	18.03	20.06	15.56	13.76	12.02	6.01
Housing and ruban renewal	10.92	35.37	16.23	10.81	20.89	14.67	6.94	1.62

*See footnotes on page 94.

Table 16 (Continued)

Per Capita Amounts of Selected City Finance Items by Population-Size Groups

Fiscal Year 1971

Item	All Municipalities	Population Size* 1,000,000 or more (7)	500,000 to 999,999 (6)	300,000 to 499,999 (5)	200,000 to 399,999 (4)	100,000 to 299,999 (3)	50,000 to 199,999 (2)	Less than 50,000 (1)
Libraries	3.37	5.58	5.51	3.73	3.98	3.53	3.64	1.90
Financial administration	3.90	5.59	6.26	3.89	5.11	4.05	3.65	2.78
General control	6.56	10.89	10.51	5.20	5.62	4.98†	5.34	5.20
General public buildings	3.70	5.76	4.27	4.00	6.24	4.34	4.35	2.41
Interest on general debt	9.91	19.49	13.56	12.79	14.37	10.17	7.56	5.93
All other	30.66	63.38	44.75	40.08	29.25	27.41	23.33	18.57
Water Supply								
Expenditures	18.45	18.90	20.23	18.28	19.31	16.61†	17.84	18.40
Other Utilities								
Expenditures	25.51	63.32	32.02	9.77†	11.48	24.13	14.23	18.51
Gross debt outstanding, total	370.91	812.52	456.67	423.21	427.29	329.67	276.89	234.46
Long-term	319.23	651.45	404.28	374.77	344.68	279.47	241.35	214.64
Short-term	51.67	161.08	52.39	48.44	82.61	50.20	35.55	19.84
Exhibit:d								
Adjusted general expenditures		461.01	299.43	213.40	218.27	185.84	154.12	112.04

*See footnotes on page 94.

Table 16
(Continued)

*Population as of 1970

**Does not include water supply and other utilities expenditures

†The lowest cost for this expenditure category is not found in cities of less than 50,000 persons

Exhibit d:

This exhibit represents Total General Expenditures minus education expenditures. The adjusted total provides a more reliable basis for evaluation because education special districts and school districts expenditures are not included in the item "education". As implied above, this may create severe distortions. Also note that it is assumed that any effect of non-education special districts does not diminish the validity of these data for other expenditure categories. In short, positive distortions are considered to be offset by negative distortions. The justification for this assumption is based on the most current data available from the 1967 Census of Governments. Special district expenditures are primarily for utilities which include water, gas, electric, and transit system expenditures. Together, all utilities special districts accounted for less than 2 percent of the total direct local government expenditures in 1967 (which excludes transactions between local governmental units and state and Federal aid). For a more detailed account see: Facts and Figures on Government Finance. (New York: Tax Foundation, Inc., 1973, pp. 231-245.

Source: Department of Commerce, Bureau of the Census.

cities in the United States exceeding a population of 1,000,000, social cost is not very significant in explaining the differences in cost for most cities. Rather, it appears that most of this social cost is borne by society in general through state governments and the federal government.

With respect to the variations in cost explained by density, there is little reason to believe that social cost contributes to this positive relationship. For instance, if we were to consider the number of blacks as a percentage of the total population to be an adequate indicator of poor people living in dense areas or "high cost citizens" we would expect this percentage to vary positively with greater total expenditures; that is, if these people require more city services. Adams' study of counties (including cities within county boundaries and 56 percent of the county's population) revealed that the number of blacks accounted for approximately one-sixth as much of the variation in per capita police expenditures as density. Moreover, despite the high population densities in black ghettoes, Adams found that, overall, greater proportions of blacks in the population were unrelated to greater total government expenditures (excluding education). [46] This suggests that rather than placing a cost burden on cities, blacks are under-serviced, and that variations in cost explained by density cannot be attributed to "high cost citizens" in dense areas. It even suggests that the influence of density on costs is understated.

In terms of specific governmental functions, substantial funds for police are allocated for traffic regulation rather than simple crime prevention, suggesting that congestion as well as higher levels of crime add considerably to this cost. Concentration also requires greater efforts to keep an area clean, and it increases both the possibility of dangerous fires and the need for greater measures of fire prevention. More intensive use of limited recreation resources might also lead to greater total cost. Thus, while differences may exist in the quality of services and the amounts of social cost between areas, these factors cannot easily be used to account for the effect of density on cost. Moreover, there is a definite need for a greater number and a greater use of services in densely settled areas.

Density Data Shortcomings and the Relationship Between Density and Size

In the final analysis, the hypothesis that density, far more than any other factor, significantly increases the cost of providing government services is partially vindicated. However, this finding is constrained by two factors. The first is the limited amount of attention that has been given to density. The only tables directly linking density to per capita expenditures for a large sample of areas are found in Adams' work. Population density in this case is based on total county land area, rather than on the far more satisfactory urbanized area. The problem is clarified by a look at Adams' findings. In all, it appears that the largest incremental increase in cost for police, fire, sanitation, and recreation occurs somewhere between 2500 and 3500 persons per square mile. [47] Thus, not only is there reason to believe that these figures understate true densities, but the spatial referent is inadequate for precision work. This lack of attention and data shortcomings generally constrain our ability to directly relate changes in density to differences in operating expenditures for education, highways, sewage, and water.

Secondly, the hypothesis is limited by the strong relationship between density and population size. This limitation requires a strong qualification of the hypothesis, but paradoxically it also supports the argument that, for public costs, we can address the issues of economies of scale and an optimally scaled city with some certainty. For several reasons, the interdependence of density and size suggests that considering either of them in isolation to the other is far less meaningful than considering them within the context they help define: urban scale. For instance, we have seen that density exerts pressure on costs and that costs rise steadily as we move from areas with smaller to larger populations. The tie between density and size here is reflected by the strong positive correlation of 0.514 that Bahl obtained for all S.M.S.A.'s. In short, as size increases, density generally increases.

Another reason is that given this relationship we would generally expect size variables as well as density variables to load positively on costs. Several studies bear out this supposition. Bahl, for instance, found that S.M.S.A. population size had coefficients of determination of 0.328 and 0.323 for total and operating expenditures, respectively. This compares to the coefficients of 0.444 and 0.526 for density that were mentioned earlier. Other studies have also found size to positively load on costs, though not always at the level of significance. These results suggest that the variation in cost explained by size, particularly for operating expenditures, may largely reflect the influence of density on cost.

Do these findings mean that size, in and of itself, has no effect on costs, and that we can attribute variations in costs as size increases solely to its pressure to form higher densities? The answer is yes in part, but this is an incomplete statement of the problem. Public costs associated with size, for example, might be waste and inefficiency in government administration or in the provision of services, or some reflection of externalities, such as noise and pollution. While any effort to specify causes here would be equivocal, we could nevertheless expect a city with an average population density of 3000 persons per square mile and a population of 50,000 to generate less pressure on total costs than a city of equal density but a population of 150,000. Furthermore, note that tests performed on density variables were made for areas of a minimum size level, such as S.M.S.A.'s with central city populations of 50,000 persons or more, and in the case of Adam's study of counties, the largest 474 counties out of a total of 3096 in the United States. [48]

In short, the variations in costs explained by density are set in a rough context of population size. We cannot therefore think of density in isolation from size, nor can we assume that size does not explain any of the variation in cost. Conversely, we cannot oversimplify by claiming that the only link between size and cost is through the relationship of size and density.

In effect, the best conclusion we can draw is that an analysis of aggregated government costs in relation to different population sizes reflects differences in groups or areas of similar urban scale or some increasing combination of both size and density. Thus, while there are ambiguities in the relationship between size and density, their strong association supports the contention that, at least for public costs, we can analyze economies of scale and attempt to identify an optimally scaled city. For this reason and the importance of government costs to planning decisions, an effort will be made to identify an optimum solely on the basis of public costs. The strength of the conclusions that can be made at this point, in turn, will depend on the impact of changes in urban scale on private as well as public costs. Thus, the analysis of these costs (which appears later) should serve to both clarify and test the validity of any findings we can made on the basis of government expenditures.

Economies of Scale and Optimal Scale for Public Costs

In terms of increasing levels of urban scale or some combination of increasing density and population size, it would appear that any economies are very limited and that diseconomies soon set in. This broad generalization has substantial support in studies of both capital and operating expenditures. Svimez' work in Italy, Schmandt's and Stephen's analysis of 1957 data, and the per capita figures provided by the Bureau of Census show a distinct increase in costs for cities or counties in successively higher size classes (except the very smallest classes). In all these cases, costs were rising at the level of scale represented by areas of 50,000 people or more.

Turning to the Bureau of the Census figures for fiscal year 1971, we can be far more specific. Despite the detailed breakdown into seven size classes, there is an almost straight line projection of increases in total general expenditures and total per capita debt for capital facilities as scale increases from the smallest to the largest cities. For individual items, on the other hand, there are several generally small distortions in this straight line projection, particularly between classes four and five. It seems remarkable though that for all but four items, the lowest operating costs and levels of indebtedness are found in cities with less than 50,000 persons.

The four basic categories for which no direct and firm relationship between density and cost could be established are education, highway maintenance, and sewage and water operating expenditures. Again, because of the incomplete nature of education data, it is difficult to draw definite conclusions. The best inference we can make is that it probably acts like the other expenditure categories, in that costs rise with increasing scale. Focusing on highway expenditures, we find no definite pattern, indicating a lack of either economies or diseconomies as scale increases. While this aggregative information does not negate the possibility of savings due to increasing densities, other evidence does not show any appreciable savings. Table 13 shows greater per capita highway costs for central cities than suburbs (note that this includes both capital and operating expenses). In Adams' study, the variation in street maintenance cost was unexplained by density, while Bahl found it to load positively, though insignificantly, on this expense. There are several explanations for these results, including greater wear and obsolescence, greater need for traffic control devices, high land costs, use of multi-level roadways, etc.

Turning to sewage costs, Table 16 shows an increase as scale increases up to cities with 500,000 to 1,000,000 people and a sharpe decline for those over one million. Also, the table reveals that areas in the smaller class pay considerably less than all other cities, indicating that economies of scale are less prevalent as size increases. Nonetheless, this evidence may not appear to be conclusive. Isard, for instance, documents the considerable economies of scale for sewage treatment plants as volume increases. [49] For overall operating expenses several factors may offset those economies, such as obsolence, high wage rates, expensive plant sites, [50] and the quality control incurred onus that falls on areas of greater concentrations of people. There is also the distinct possibility that several smaller capacity plants in certain areas have been retained over the years rather than consolidated.

For water operating expenditures there do not appear to be any appreciable economies of scale. Water supply expenditures vary according to size class much like highway costs. For other utilities, in contrast, what appears to be a significant economy of scale for areas of up to 500,000 people is disrupted by the high per capita costs in class three. If this is a unique distortion, there may nonetheless be considerable economies of scale for this service.

Briefly, in cases where we normally expect lower per capita costs, it appears that generally any economies associated with increasing size and density are negated quickly by other factors such as difficulty of delivery or excessive use. In contrast to other city expenditures, they generally do not show significant diseconomies of scale.

On the sole basis of government costs, an optimally scaled city appears to be best represented by those areas with populations of 50,000 or less.

Specific Physical Costs of Greater Urban Scale

From the analysis of government costs our hypothesis of greater costs due to density, either for greater concentrations of population or buildings, or both, is partly vindicated in several respects. Also, when density is considered alongside size, we find steadily increasing costs with increases in scale. To gain a greater understanding of the specific nature of these costs, their causes, their validity as a basis for optimal scale for public costs, and their implications for TOPAZ and land use development, we can turn to the work of P.A. Stone. His analysis is summarized below for private as well as public costs associated with density and height on the one hand, and redevelopment and space needs on the other hand. His sample consisted of cities in England exceeding a population of 50,000 persons, while much of his information is drawn from ten years of empirical observation as a planner and economist.

In terms of density and height, Stone found that all multi-level use of land tends to increase both capital and operating costs for housing, industrial, or transportation purposes. A tenfold increase in the number of stories per unit of land, for instance, was found to result in no more than a doubling of either population or building density. Stone attributes his finding to diminishing returns from increasing the number of stories, the need for greater space around a tall building, and the increased demand for road and parking space to handle the higher generation of traffic. [51]

In addition, Stone found that, per square foot of floor space, both development and operating costs for blocks of eight story residences were approximately 50 percent higher than for blocks with one and two story buildings. Greater development costs were partially attributed to the cost of vertical transportation, while higher operating costs were attributed to additional closed access space, the cost of cleaning building exteriors, and greater use of an artificial environment [52]

For highway costs, Stone produced figures which showed cut and cover costs to be approximately 15 times greater than the cost of surface road development, while tunneling was about 50 times greater. [53]

In terms of redevelopment costs, Stone made several pertinent comments. Not only is development on previously developed ground far more expensive than on virgin ground, but it is constrained by increasing needs for space due to family fission, greater demand for large room sizes, privacy, recreation space, roads, and parking space. These demands cannot be readily met by redevelopment of small dense sections of a city, except at great costs due to high land values. Should government attempt to rehabilitate such areas, Stone asserts that in the long run, conversion to a less dense use is least expensive. High initial costs are often too strenous a burden for government to assume. Thus, some sections of the central city are left to decay.

Stone's analysis of transportation is also revealing. He noted that more intensive development and closer groupings of land uses result in significantly reduced distances over which most trips are made. In this case, "traffic generation becomes more intense and the savings in both the costs of road development and journey costs tend to be small." From studies of the National Institute of Economic and Social Research (NIESR), Stone illustrated that increasing standard housing density by 25 percent only decreases road development and journey costs by approximately 2 and 4 percent, respectively, and that only an additional one-third increase in housing density appears to result in any further savings. These savings would be more than offset by the additional costs of developing and operating the housing. [54]

Non-cluster cities provide a sharp contrast. Increases in size for these cities substantially increased main road development and journey to work costs. The NIESR studies showed that journey to work costs rose by 25 percent for increases in city size from 50,000 to 100,000, and again by 50 percent for increases from 100,000 to 250,000. [55] Since travel costs are borne by the user and capitalized far more regularly than roadways, increases in population for unclustered cities result in significant transportation diseconomies. These diseconomies may be only partially reflected in an analysis of government costs.

In summary, Stone concluded that any economies of city scale, either in dense or sparsely populated areas, would probably be used up as a city approached a population of 50,000. [56] Beyond this point, significant diseconomies may set in for both public capital and private capital and operating costs.

Questions of Optimality

With this evidence of a more expensive total living environment as scale increases, we can more adequately address three related issues about optimality and discuss their implications. They are: (1) the strength of a population threshold of 50,000 as an indicator of a limit to optimum scale, (2) whether or not there will be cost advantages for small cities growing to a population of 50,000, and (3) the effect of scale with respect to redevelopment costs of cities doubling to a population of 100,000, compared to those doubling to a population of 50,000.

Having identified several highly interrelated factors that may contribute to a rise in total costs, can we reasonably conclude that as a city grows beyond a size of 50,000 persons, the cost of providing a constant or increased level of both private facilities and public services and facilities will substantially increase? Under general conditions, the evidence convincingly suggests that we can. The strength of this assertion will be tempered by the unique characteristics of each city. We might imagine an efficient city of 200,000 with total physical living costs comparable to some cities of 50,000 and certainly some of 100,000 that are exceptions to this rule. But on the average, we would have to recognize the conformity of cities of different size class to distinct patterns of differences in aggregate costs.

We have noted the interrelationships between size and density, and density and rent. The last tie is well established in the literature so it is not treated thoroughly here. It is only necessary to note that rents are generally several multiples higher in the dense center of a city than on the periphery, and that there is a direct relationship between a high premium on land and more intensive land use. [57] Conversely, more intensive land use and hence the amenities of proximity and convenience, generate higher land values. The analog is that cities with the highest densities are those with the highest rents. [58] This means, in effect, that we might find considerable differences between cities in the same class in specific costs, but the overall effects of their similar scale would exert an equalizing influence on total costs. In short, if the relationship between size, density, and rent is steady enough, we would expect to see the same incremental effect on costs showing up between all of several population size classes. This is seen in the case of government expenditures for both operations and capital facilities, except in one instance. Thus, while there are undoubtedly exceptions (as will be later illustrated), the interrelationships are strong enough so that we can be quite specific.

In a general sense, this means that when cities roughly exceed a population of 50,000, we can expect per capita physical costs to rise. Differences in density may be the basic exception here, although it does not appear to provide that much leeway for savings. Consider the city with moderate densities as defined by 2500 to 3500 persons per square mile (and conforming to Adams' findings). If density is increased, we would expect costs to rise noticeably. On the other hand, if density is significantly reduced, we might achieve some savings (e.g., rent). In either case highway maintenance costs would probably be relatively equal. But in the latter case, transportation costs would rise considerably.

Turning to the second issue there appears to be some evidence of a "U"-shaped curve, at least for capital facilities, within the class of cities or counties with less than 50,000 persons. This, in turn, might lead us to conclude that by growing to this approximate size, cities will benefit by taking advantage of economies of scale. This conclusion may be wrong for several reasons as substantiated by the same figures used by Schmandt and Stephens and others to illustrate economies of scale. Economies of scale may exist for some facilities and services in this size class, but there is little to indicate that they are not offset or somehow dissipated after a city or county reaches a population size of 5,000 persons. For cities in Italy, Svimez found that per capita costs for cities of 5,000 were $128, while they were $102 for the 5,000 to 20,000 class and $100 for the 20,000 to 50,000 class. Schmandt and Stephens analysis of counties (which should be noted for their incomparability with cities, particularly at this level) showed a mean per capita indebtedness of $128 for counties under a population of 5,000 and

$109 and $113 for the classes of 5,000 to 14,999 and 15,000 to 24,999, respectively, and steady increases thereafter.

What this illustrates, in essence, is the futility of attempting to identify an optimum at such a fine level of detail or hoping that by expansion of the population to 50,000 the largely unguided, incremental growth characteristic of American cities will achieve significant economies. The important point is that we can roughly identify a threshold for optimum city scale of populations not exceeding 50,000.

A third question we can address relates to the effect of scale on redevelopment costs of cities doubling in population. By examining this question, we can look at the question of optimality from a different perspective and more specifically illustrate exceptions to the rule. Stone asserts that in the case of doubling the population of a city of 50,000 persons, it would be cheaper to simply build a twin. [59] In support of this proposal, it is useful to consider the succession of land uses which occurs as a growing city adjusts to the increasing burden on its physical structure and facilities. As Stone implies, it may be necessary for cities above a population of 50,000 to widen roads, run new highways through previously developed areas, clear land for parking space, replace other capital facilities, such as sewer and water treatment plants, lay additional water and sewer collector lines alongside existing ones, construct higher buildings, etc.

On the other hand, if we consider the possibility of a city doubling to a population of 50,000, it seems likely that at this smaller scale, the capacities of existing structures and facilities would not be so greatly strained. For instance, instead of adding a new highway, it may be only necessary to widen one. Also, if the densities are generally low for cities of 25,000, it would appear that with more vacant land interspersed between the existing population, growth could be generally accommodated by development on virgin land, or at least less redevelopment.

The possibility of this being generally true depends on the relationship between size and density at the scale of 50,000 persons or less. Because the positive correlations obtained by Bahl applied to cities above this size class, an original analysis was made of all independent Virginia cities in this range with 1970 data. To compare densities within this class, average density was determine for those cities under 25,000 and for those cities between 25,000 and 50,000 persons. The true population range was approximately 4,000 to 24,500 and 36,000 to 47,000. For the 24 cities in the lower range, there was an average of 2200 persons per square mile and 3470 for the three that comprised the larger range. These contrast with densities in the two largest Virginia cities, Norfolk and Richmond, of 5800 and 4140, respectively. [60]

From the standpoint of vacant land, we can turn to Northam's study based on the 23 Oregon cities with less than 50,000 persons, and 86 of the 130

United States cities in 1960 with populations over 100,000. The average amount of vacant land as a percentage of total city areas was 37.9 for the Oregon cities and 19.7 for the others.

This partial information illustrates exceptions to the rule by requiring the qualification that many variations exist with respect to both density and vacant land. The most dominant exception is found where cities are located within larger metropolitan areas. They must be considered a part of the larger whole they make up, and distinguished from relatively free standing cities. For instance, in the analysis of Virginia data the small cities of Falls Church, Fairfax, and Suffolk are found to have a combined density of 4200 persons per square mile. This reflects the densities of the Washington, D.C. and Norfolk, Virginia S.M.S.A.'s of which they are a part. Other unusual characteristics relate to form, where a centralized development pattern is severely distorted by an elongated shape. A beach resort is one example, while cities stretched along highways are another.

Even though there are many unique characteristics among cities, the evidence shows that in general small cities, particularly those below a population of 25,000, can grow substantially without the need for as much redevelopment or without placing as great a strain on existing resources. On the other hand, those cities with populations of 50,000 generally would not have the same excess capacities for future growth. This suggests the qualification that for cities of 25,000 with relatively high densities, it would be cheaper to build a twin rather than double its size.

In summary, despite many differences in cities, data compiled for several years from a variety of sources indicate that generally costs begin to rise steadily as scale increases beyond the level of 50,000 persons, while costs do not appear to be appreciably different for all but the smallest cities within this size class. We can easily imagine leeway for adding to the population of a city of approximately 50,000 persons, particularly where densities and rents are low or where services are efficiently provided. But in the American tradition of unguided, haphazard growth, we can readily see the potential danger of rising physical costs as scale increases beyond this point.

Conclusion

From a look at government expenditures and debt and Stone's work, several conclusions can be drawn. In terms of the hypothesis that higher density demands increased physical costs, both population and building density can be said to be generally responsible for raising costs for several categories of government expenditures, such as police, fire, sanitation, recreation, and in some cases, noncapital sewage and general control. Because of the difficulty of identifying social costs in government budgets, it is not possible to say with certainty how much of the increased cost is reflected by social rather than physical necessity. Nonetheless, for most cities we can surmise that it is relatively insignificant. Moreover, Stone's investigation of the private capital and operating costs for housing in dense areas, particularly when dwellings are built well above ground level, reveals a high physical cost. A look at costs of redevelopment and non-ground level highway construction in areas of high density also reveals exorbitant physical costs. In addition to these costs and related to them are the higher land values generating and/or generated by greater concentrations of land use. While greater land rent would tend to increase the cost of providing government services, rent may be the greatest cost in densely settled areas primarily borne by the individual. In fact, it would appear to be more significant to the average individual than the added cost of government services and facilities.* In the final analysis, it is evident that greater densities, within the rough context of a minimun size, lead to considerably higher total living costs.

Focusing on the relationship between density and size, we find several important implications for land use development decisions. First, we associate greater transportation costs with increasing population size, particularly for non-cluster cities of more than 50,000 persons. Secondly, size in a rough context of city dimensions and a minimum density may be more directly responsible for some of the pressure on total government costs than density. Possible explanations for this hypothesis include pollution and inefficiency and waste in government administration and the provision of physical services. Thirdly, what we appear to have in terms of cause and effect, is size generally leading to or meaning greater density, with density more directly affecting cost than size. Finally, because of the strong relationship between size and density, we must consider them in their urban scale context, interpreting data for cities by population size class as a reflection of scale and differences in scale.

In terms of variations in urban scale we find little or no evidence of any appreciable economies of scale for water and sewer operating expenditures, or highway construction and maintenance costs in cities exceeding 50,000 persons. Furthermore, in large scale cities we would expect to find diseconomies of scale for other expenditures and for overall living costs. More specifically, this means that some combination of greater amounts of money are usually expended for housing, commercial, and industrial structures; police, fire, sanitation, recreation, and transportation services; and most other public capital facilities. Also, while the costs of growth do not initially show up in government budgets, growth leads to greater scale and most probably to higher dollar costs borne by the public as well as private sectors. Thus, if optimally scaled cities can be said to exist in terms of physical costs, they are best defined as those with populations of 50,000 or less.

*Purchases of land do not necessarily represent transfer of payments as is sometimes assumed. This is only true where a purchaser in the end does not pay more than the original face value of the property. Moreover, land value obviously cannot be considered a transfer payment to the renter.

Based on these findings, we can see several important implications for TOPAZ. Where low development costs result in greater concentrations of land uses, we must be particularly careful to incorporate appropriate planning standards into the technique's inputs for residential densities and park space per resident, etc. Also, rather than applying the technique to one center and thereby reinforcing a centralized development pattern, we should consider the feasibility of decentralized or even nucleated development.

These patterns lead to questions of economic performance. Thompson and Richardson associate performance with large population size, where a diversified economy generates its own growth and is less subject to cyclical fluctuations. The point is well taken, but a nucleated pattern (e.g., Stockholm) of several well linked clusters rather than one amoeba-like form may be far less costly while accomplishing the same task. Stone claims that given the option of doubling the population of a city of 50,000, it would be cheaper to simply build a twin city.

To illustrate this point more dramatically, consider land value or land rent. If development in a region is centralized, extremely high rents at the core are almost inevitable. If rents are shown on a relief map, we would expect to find a high cone clearly delineating the center. If there were several cones of the highest size, however, we would not expect any of them to be so highly peaked. In short, we would expect a more equal distribution of rents over the land surface, which might be equivalent to much lower total costs for the living environment. [61]

The evidence and conclusions we can draw clearly indicate a possible advantage to such an approach, one which can be readily adopted to testing by TOPAZ.

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Part IV

ALTERNATIVE ORGANIZATIONAL, LEGAL, AND FINANCIAL MECHANISMS FOR IMPLEMENTING TOPAZ RESULTS

Introduction

To have any practical value, the decisions coming from the application of TOPAZ must be implemented within the overall urban context involving legal, political, physical, and financial constraints. This part will attempt to outline various organizational, legal and financial mechanisms which could be used to promote the most efficient pattern of land use activities suggested by TOPAZ. However, it should be emphasized that this system of controls could also be used to promote a pattern of land use activities established by any method. Also, while this section deals primarily with land use in Blacksburg, Virginia, the ideas contained herein could be employed by any locality, after making the necessary adjustments to take into account the local and statewide political climate, community needs, and legal constraints.

Present Arrangement

The most obvious structure for administering land use controls is the present one. Indeed, this is quite acceptable and desirable to town officials; however, there are definite limitations to this arrangement in addition to its advantages.

Blacksburg operates under the council-manager form of government. The town manager appoints the town planner, who is head of the planning department, which is part of the planning commission. Any planning recommendation originating in the planning department must be approved by the entire planning commission and then by town council before becoming operative. This is no different from the procedure used in many towns and cities. The advantages seen in this system by town officials are: (1) the elected representatives of the citizens have the final say on any proposal, (2) all actors in the process are at least indirectly responsible to the voters, (3) no one department is able to exert undue influence on another, (4) all necessary and proper functions are performed.

Disadvantages in this system which should be pointed out are: (l) frequent lack of coordination among departments, (2) varied and often conflicting goals and policies among departments, (3) many opportunities for political pressure, (4) competition for limited resources such as land and money.

What does this mean in terms of town development? That which is deemed necessary and desirable after all the political maneuvering has taken place will eventually come to realization. All the constraints discussed in the first section come to bear on these decisions. Granted, all the necessary elements for controlling growth are present, but the efficiency of their use is suspect.

Rather than dismiss the present system as unworkable in the face of expected growth, we here suggest certain modifications which could be of great help. First, the planning department consists of one trained professional planner who serves at the pleasure of the town manager. His professional advice is often ignored or subordinated to the wishes and incomplete understanding of self-interest maximizing politicians and other influential citizens. To justify the existence of the planner, he must be given the power to exercise the responsibilities which he has been trained to accept. Secondly, an efficient means of communication must be established among departments. This includes knowledge of the programs of all agencies and coordination of budget requests and projects. Lastly, land use controls not presently in use in Blacksburg should be investigated, and those which are feasible and useful should be adopted.

Local Development Corporation

Publicly-owned, non-profit development corporations are usually established to promote industrial growth in a city. The Philadelphia Industrial Development Corporation (PIDC) is a good example. This was incorporated like any other non-profit corporation as a joint venture of the City and Chamber of Commerce, and influential businessmen and industrialists. The PIDC is empowered to buy or otherwise acquire, sell, lease, and develop land for industrial use. It began with a fund established by the City government and a land bank developed from vacant land owned by the City. The PIDC now operates with a revolving fund which is used to buy suitable land and is then replenished by money from sale or lease of land. Land has often been acquired from the redevelopment authority in Philadelphia. The corporation also has the power to issue bonds to finance projects. Overall results from this operation have been highly successful.

The PIDC grew out of a division of the Department of Commerce of Philadelphia. While there was some doubt about creating an autonomous corporation with such vast powers, several advantages have been realized over the old structure. Freedom to hire and fire and flexibility in location are two such advantages, but "perhaps the main advantage to be gained by incorporation is financial autonomy. The normal departmental process of estimating financial needs for a year in advance does not lend itself too readily to operations of a business nature." [1]

Local Development Agency

Local development agencies are becoming more popular in the United States. Connecticut and a few other states have been leaders in adopting their use. The purpose of such agencies is to consolidate scattered and uncoordinated governmental functions. Specifically, a typical agency will include the former building official, board of appeals, and planning commission. Minor legislative functions, such as making small changes to the official map, would be granted to this agency also.

According to the American Society of Planning Officials' plan for Connecticut, local agencies would have to meet three requirements before being allowed to operate by that state. First, the agency would have to submit a development guidance program for approval. This would explain principles used in establishing zoning boundaries and would state policies used to relate regulatory decisions to other key decisions. Secondly, a capital improvements program would have to be submitted. The third requirement is proof of professionally competent planning assistance. These development policies would be local laws rather than mere policy statements. [2]

A broad spectrum of powers should be available to these agencies, but with provisions made for appeal to a regional or state agency. Mandatory dedication, expanded zoning and subdivision powers, eminent domain, advance land acquisition, and planned unit development regulations are some of the powers envisioned for the agencies.

ALTERNATIVE LAND USE CONTROLS

This section will attempt to describe some of the various methods of implementing land use controls. In describing these various methods, it will demonstrate that each method has certain implications to the participants involved. Hence, as various policy instruments shift, one will observe a shift of effects on the participants. In this manner, actors will be identified while at the same time benefits and nonbenefits will be assigned as each policy method is examined.

As a first step in the investigation of land use controls, we need to clarify, classify, and define the basic objectives and functions of land use control policies (this is otherwise referred to as a method of analyzation). In developing such a method it becomes necessary to reevaluate some of the basic concepts which govern our urban life. One concept we must reevaluate is land ownership. The basic issue concerns who should own urban land and what rights should the owner possess. For the purposes of this paper, the latter question will be of primary importance. Throughout history, land ownership has been closely associated with political and economic power. In this country, democracy began as a system which gave the vote to him who had proven his worth by becoming a landowner. [3] There were very few restrictions on his "right" to do whatever he wanted with the land he owned. Our concept of land ownership was governed by the belief that the best interests of society would be served if each individual land owner had maximum freedom. In early American history, we encouraged the development of frontier land by private interests. We did this by guaranteeing and protecting their rights in the land that they acquired and developed. This early concept of land ownership served the best interests of society at that time. [4]

In analyzing the various policies concerning land use control, a criterion for analyzation will be whether it serves the best interests of urban society today, based on the assumption that land in and around urban areas is a scarce resource. The best interests of society can be defined in many terms and from many different points of view. Here the interests of society will be defined as each policy for land use control is examined.

The general factors of analyzation for land use control policies are: (1) Social-Cultural--does the control encourage harmony or friction among segments of the society or foster a sense of community? (2) Political-Legal--to what extent do land use controls affect a political and legal response? (3) Economic--what is the feasibility of the specific land-use control in terms of public and private costs and benefits? (4) Natural--what effect, or lack thereof, does a specific land-use control have on the natural environment? (5) Physical--does a specific land-use control policy have an effect on the way man orients his physical environment? (6) Aesthetic--what are the aesthetic implications of certain land-use controls? Certain policies will emphasize certain factors of analysis over others.

Mandatory Dedication

Under many subdivision control enabling acts, counties, towns, and cities are authorized to adopt reasonable regulations and provisions that relate to adequate drainage and flood control and other public purposes. These include the manner in which (1) streets are constructed and repaired, (2) water lines and storm and sanitary sewers are built, and (3) other utilities or facilities are installed. Developers are required to provide streets, curbs, gutters, sidewalks, sewer lines, water lines and storm drainage facilities to service their own subdivisions. But new residential subdivisions create a demand not only for these facilities, but also for parks and schools. [5]

The issue of who should pay for major facilities, such as parks and schools, has been a point of concern to all local governments and private developers. It is now generally acknowledged that public open space is a necessary part of new residential subdivisions. With man's increasing demands on the resources of his land, open space enhancement will be increasingly concerned with the protection of the natural environment. Under the policy of mandatory dedication of park and school land, the developer is required to set aside a segment of land for the purpose of park and school development. This policy has several benefits for the community at large. First, the community can build schools as they are needed and not have to absorb the extra cost of purchasing land at an inflated rate due to surrounding development. Secondly, if school sites are known in advance, safety conditions can be enhanced by not building main roads in the immediate area. Finally, externalities will be avoided--the developer's cost of providing open space necessary to serve a subdivision will ultimately be passed on to the purchasers of the subdivision dwellings as a part of the purchase price. In this manner, the community will not bear the cost of purchasing the land when the developer has continued developing without considering the needs of the community. [6] Thus any requirement that a developer provide facilities or open space areas is a form of a user tax, borne by the eventual purchasers of dwellings within the subdivision. [7] This policy seems to bring costs, benefits, and consequences into proper alignment. Under this policy, however, the community still pays the actual construction costs of a new school, and these costs far exceed the cost of the land on which the school is built.

We will now examine some of the abuses of this policy and their effects on the participants. Some municipalities have attempted to procure specific sites through a case-by-case rezoning process by "bargaining" a school site in exchange for the granting of a higher-density zoning classification. This technique contains many opportunities for political considerations only to play a major role in school and park sites. For one thing, only large-scale developments are required to dedicate land for school purposes, with the result that all developers are not treated equally. [5] This leaves open the possibility of developers building in an incremental fashion, thereby keeping their developed areas small enough to avoid site dedication. This incremental building would also force government to expand its services in an incremental fashion, thereby increasing its costs.

What other considerations should be kept in mind if the policy of dedication is to achieve its desired goals of (1) providing for orderly development and (2) reducing externalities? First, there should be a limitation on the amount of land the community may secure through such a provision. Obviously, a community could stifle development if developers feared that a great number of acres would be lost to mandatory dedication. In other words, to keep the policy functional, compulsory dedication in most cases should extend only to the amount of land actually needed for school and park use by the residents of the new subdivision. For example, a development with single-family detached dwellings will need more school and park space than apartment complexes, such as those now present in Blacksburg that house primarily college students. Standards for dedication should be fluid enough so as not to discourage a development that will meet the needs of a segment of the community. [8]

These limitations would be overcome if dedication were used in conjunction with TOPAZ. TOPAZ not only determines how large a school or park site should be, but also where it should optimally be located. What if the optimal location is not within the development chosen? And what if the development is not large enough to support a school or park? In either case, the developer should be required to make a payment in lieu of dedication. The fee should be based on the demand created by the development and the average cost per acre of school and park lands in the past. In all cases, the option of dedication or payment should be exercised by the local governing body.

Payments must be used for land purchase immediately in order to avoid inflated land costs later. They must also be used only for school and park sites. Any other use would invite court action on the grounds of undue extension of police powers.

Eminent Domain

Another land-use control commonly used by local government is eminent domain. This is a means of acquiring land deemed necessary for the good of the community, such as for highways and utilities. It cannot be used too frequently though, because the "good" must be a tangible one and relatively immediate. The courts have struck down acquisition by eminent domain if it is used indiscriminately because such acquisition would probably be considered a deprivation of property without due process of law. In other words, the government must have a very good reason for taking the land.

Under eminent domain, the government must also give just compensation to the property owner. This is another reason why government cannot use this device too frequently--most localities simply cannot afford to buy properties in quantities significant enough to control development. However, there are some cases where controlling a single parcel can effect control of development over a much wider area. In these cases, where legally feasible, eminent domain can be utilized to the fullest.

Eminent domain is a handy tool along with other land assembly techniques when there is one holdout seller in an entire development. If eminent domain were used against these holdouts, costs of taxes on idle property already assembled, interest, and other carrying charges would be greatly reduced.

Real Estate Taxation

Another means of implementing land use controls is through two methods of real estate taxation. These are (1) preferential assessment, and (2) deferred taxation. Under the former, the assessment of farm lands and open space is based solely on their actual use value rather than on their fair market value.

Deferred taxation is also designed to lighten the tax burden on owners of open space lands in a transitional area, but it provides a means of recouping lost tax revenues when the lands are developed for urban uses. [9] The assessor establishes two assessments for open space lands, one at actual use value, the other at fair market value taking into account the value of the lands for urban development purposes. So long as a parcel of land remains in open space use, the owner pays taxes on the basis of the low, use-value assessment. When the land is developed or sold for development, the owner must pay all--or a specified portion--of the additional taxes that would have been due over the years if the high, fair-market value assessment had been used to compute the amount of tax. "Thus, deferred taxation is a technique whereby an owner of open space lands obtains a tax advantage while the lands remain in open space use, but the local government obtains full tax revenues for the open-space-use period when the land is changed over to urban uses." [5]

These methods have been considered by some as means of preserving open space areas without the necessity of public purchase. [3] Many farms, especially on the urban-rural fringe, are being driven out of use because of sharp rises in taxes. The tax rise has occurred because of the current scramble for open suburban land (usually by speculators) on which will be built large residential subdivisions which will demand urban type services, such as roads, sewers, and schools. Farmers, of course, do not benefit from these new services and therefore must take the new, higher taxes out of their meager profits. They are practically forced to sell out, far in advance of the actual development, because they do not have the extra funds to pay the increased assessments and hold their acreages long enough to get the price the speculators obtain when the land is eventually sold for housing and other urban uses. [10]

The real defect in the position that preferential assessment and deferred taxation techniques preserve and maintain open space is a basic misunderstanding of these controls. For example, a developer may see that it is impossible to obtain a certain parcel of land because it has been given this preferential treatment. He might then purchase land just beyond this area where land values and taxes are still low. He will then develop this land for residential purposes. This leap-frogging more than likely will cause the municipality greater problems in delivering services because the development is even further away. [3] If the developer chooses not to develop the land for a while, he also will get a tax break due to urban growth pressures. This policy thus would be protecting those people that it was designed to protect against.

In spite of the tax relief provided by the preferential assessment and deferred taxation techniques, the principal and dominant incentive to develop or sell for development remains the profit that the owner can obtain by developing his land or selling it--a profit that will far exceed that which can be derived from farming, foresting, or other open space use. [5]

The result of the leap-frogging mentioned earlier not only has adverse political and economic effects on the community but also adverse environmental effects. In many cases it wreaks havoc upon the countryside, destroying field and stream.

European Taxation

European countires have traditonally imposed a variety of taxes on land and land transactions as a means of controlling development. Sweden imposes a tax on capital gains and income for land as shown in Table 17. This tax discourages ownership for short periods of time for speculative purposes.

Table 17

Tax on Capital Gains and Income in Sweden

Length of One Ownership	Tax on Gain
Less than 7 years	100%
7 Years but less than 8	75%
8 to 9 Years	50%
9 to 10 Years	25%
10 or More Years	0%

Several countries administer a progressive tax as property valuation of a single owner increases. The main disadvantage with this is that it encourages the fragmentation of land.

In Denmark, "when agricultural land becomes ripe for development as a result of urban extension, an annual land increment tax will normally be levied on the basis of the eventually higher value of the land. In addition, Danish authorities tax at least part of the cost for the installation of sewers and sometimes of roads." [11]

The United Kingdom places a tax on gross income from land. No allowance is made for depreciation, maintenance, or management costs.

Easements

Utilization of easements is another popular mechanism through which land use controls are implemented. Bascially, an easement consists of buying one of the rights from a man to his property in the form of rights-of-way for sewer and other utilities. Easements are worth what the owner is giving up and as a result costs vary.

The gross easement allows the locality to purchase rights on a man's property even though it does not own property nearby. There is some legal question as to the extent to which this can be applied since controls that are too sweeping may present a problem of deprivation of property without just compensation and due process of law. The appurtenant easement is much more easily applied because rights purchased will apply directly to a parcel for which the easement is sought.

Most easements are for perpetuity, but there is almost always a reverter clause that in effect states that if the purpose for which the easement was sought is abandoned, the easement will automatically be voided and all rights will return to the owner of the land.

There are several benefits to the use of easements: (1) it preserves open spaces without the community having to buy them; (2) land remains on the local tax rolls; (3) there is no maintenance burden on the locality; (4) the owner keeps his land; and (5) in some cases, property taxes will be eliminated or open space will continue to be assessed at open space value and not developmental value.

Land Banks

Another land-use control mechanism that has been proposed is the land bank, in which communities are authorized to purchase strategically located, undeveloped lands to be held by the land bank until the land is ready for private use. This technique would be a more effective way to prevent unwise or untimely development than policy-power legislation, such as zoning and subdivision control regulations. [3]

But this technique would encounter many difficulties. In the face of a decreased tax base, debt limitations, and demands for other services, governments would rarely have money to buy any substantial quantity of land on the open market. Secondly, a land-purchase program can be certain to meet political resistance in many communities. Can a local government successfully justify owning land that is not being used, while its poor suffer in squalid slums or its schools need renovating?

Another reason this might not be a wise policy is that undeveloped land is often held in small parcels in separate ownership. As a result, it is difficult to assemble tracts large enough for the desired purpose. Such a program would also require too much government control and red tape, something that citizens in a town such as Blacksburg abhor. It the government were to buy land, an excessive amount would be removed from local government tax rolls for substantial periods of time. Finally, if the land were bought to prevent immediate development of private property, legal problems of fairness arise that would not come about if the land were bought outright for public use. [12]

Zoning

Zoning codes limit land uses and the size and location of buildings in most areas already developed or about to undergo development. These statutes outline town plans with broad strokes. Frequently they prohibit certain uses or types of building completely, whereas an appropriate exercise of administrative judgment in particular cases might reveal that some of those uses among the restricted class possess no objectional features. [13] As a result, the use of variances becomes common, thus increasing the decretion-ary power of zoning boards. Zoning discretion continues to operate without adequate expert advice and without the political attention and control which should attach to policy decisions. [13]

Single use zoning applies poorly to large developers because builders would not be allowed to vary shapes or styles within their community. The single use concept would tend to increase congestion at key nodes and frequently make cities and subdivisions aesthetically monotonous. Unity of use may also mean that streets are devoted to activity for one part of the day or night but deserted for the rest. These empty streets may be more conducive to crime than those where a diversity of uses ensures constant activity. [14]

Zoning boards of appeal have become in effect quasi-planning departments. [15] The modern metropolitan area sees an enormous number of appeals. The vast majority of these appeals request variances from the zoning ordinance. It was reported in 1955 that over 2500 of the 9000 permit applications processed in Philadelphia were appealed. [16] In many cases vast majorities of all appeals are successful.

In granting these variances, the boards must make semi-formal policy decisions. The variance represents a conclusion that the overall benefit to the community outweighs the annoyance to the neighborhood affected. Nor is nuisance the only factor applied in deciding what uses or structures to allow in an area. [14] For example, an industrial plant, besides producing too much noise for the residents nearby, may produce too much traffic for the local roads to handle. Do the increased tax revenues justify the expense of widening the roads? Are the tax revenues sufficiently important to the good of the whole community that a few members of that community should live near a source of discomfort? Each application for a building permit that raises these sorts of questions requires a response based both on technical judgments as to the impact of the proposed use on the area and policy judgments as to the kind of community most of its residents want. [17]

This discretionary power of zoning boards has very serious social implications, especially in regard to suburban areas. Now, for the first time in history, more Americans (a total of 76 million) live in the suburbs than in either the cities (59 million) or in the predominantly rural regions outside the metropolitan areas (71 million).

There is no dispute among the experts as to the originial cause of this phenomenon: It is the rapidly accelerating flight by the middle class from the decaying central cities, with their slums, ghettos, increasingly bewildered populations of the poor, black, and elderly. Now this flight has been joined by a massive new exodus. In city after city, hundreds of major corporations have moved their plants from urban to suburban settings. One reason why they have been able to do so with such ease is that many local zoning boards of appeal have been more than willing to grant variances and exceptions to accommodate industry's presence. This is a direct result of the boards' vast discretionary powers.

Such corporate migration has created a vast, new blue-collar job market in the suburbs--but one that is, for the present, inaccessible to many urban blue-collar workers the corporations have left behind.

Many urban communities have restrictive zoning laws that ban the sort of federally subsidized housing that would permit the urban poor to settle near potential jobs. In the New York suburbs, for example, it is estimated that 150,000 of the 750,000 new jobs created during the last decade were blue-collar jobs [17], but the number of blue collar workers who found homes in those suburbs during the same period increased by only 50,000. Here one sees zoning as a land-use control that is helping to prohibit the use of land to one segment of the society.

"Snob zoning" as discussed above, takes several forms. There are zoning regulations that prohibit the construction of either small-plot (quarter acre or less) single family units, or any multiple-unit housing at all.

In defense of these practices, suburban leaders argue that even a modest influx of low-income families usually places an intolerable burden on already strained services. As Fried demonstrates in Housing Crisis U.S.A., there is no denying that even federally subsidized low-cost housing rarely "pays its way" in suburbia. [18] First, it fails notably to enlarge the property tax base. Since low-cost housing is usually inhabited by families with more children than the norm, it invariably requires higher public expenditures for schools--an item that already composes the largest part of most community's budgets. Another argument that is made forcefully at most rezoning hearings is that exclusive zoning helps preserve a suburb's quality of life. In other words, higher population densities invariably produce higher rates of crime, welfare, and pollution.

Such zoning regulations have political implications as well. The solution usually proposed in lieu of zoning changes is the equalization of property taxes throughout a county or state, with dozens of communities sharing the same tax-revenue pool to pay for their schools, police departments, and recreational facilities. [15] Thus a community with a tax base that could not support an influx of the poor would be sustained by neighboring communities with a more solid tax base and fewer low-income families. Obviously, such a radical broadening of the taxing jurisdiction would meet stiff opposition from most suburban legislators, particularly those representing middle- and upper-class constituencies. Yet this possibility may become a reality, as suggested by a recent decision by the California Supreme Court. The court ruled that the state's entire public-school-financing system, which is based on the local property tax, is unconstitutional because it favors rich areas at the expense of the poor.* The point is that property taxes and zoning are heavily related, thereby implying that zoning as a land-use control has many social, political, economic, and legal ramifications.

Rezoning Taxes

Another land-use control policy takes the form of a tax on the granting of the rezoning applications. The owner of the land to be rezoned would be required to pay a tax computed as a percentage of the difference in value between the land as originally zoned and the land as rezoned.

There are two basic reasons behind such a tax. First, it should provide a portion of the funds necessary for new public facilities, such as schools, that eventually are necessitated by the rezoning. Second, it should reduce the

*The decision was later reversed by the Supreme Court.

great profit motive that sometimes results from rezoning, causing municipal officials to violate the public interest. [19]

There are also basic problems with a rezoning tax. It assumes that all rezoning to a more intensive use confers no benefit upon the community and that the only way to secure any community value is to tax the private profit out of the more intensive use. [5] In the case of more intensive residential rezoning, an obvious benefit to the community is that it can help retard the pattern of urban sprawl. In the case of rezoning to permit commercial or industrial uses, jobs and necessary services are provided for residents and the tax base is increased.

Conditional Rezoning

Closely related to zoning as a land-use control is the technique of conditional rezoning. Here, the applicant makes some representation as to the intended specific use of the land if the rezoning is granted. [6] In many instances the representation is nothing more than a generalized statement of a particular type of use. Sometimes it is adhered to, and other times the stated type of use upon which the rezoning was partially granted exhibits few of the features that were described.

One way to remedy this situation is for the municipality to implement the conditional rezoning technique. The zoning board would have the authority to attach reasonable conditions with respect to use, site layouts and design, and time schedule for development. [5] This would permit local government to ensure that actual development would follow the representations made in connection with the rezoning application.

There are also many speculative reclassifications that are sought without any intention of developing the rezoned land in the near future. These can have serious effects on the overall development of an area. If, for example, the developer indicates at the rezoning hearing that he wishes to develop a new neighborhood, but in reality he has no intention of doing so within ten years, a serious problem is created for the local government. It will not rezone land next to the parcel for industrial purposes because the uses might conflict, thereby reducing the economic potential for surrounding land. Secondly, the local government might include, for the next fiscal year, the tax revenue it expects to receive from the rezoned land and set its expenditures accordingly. This problem could be remedied by imposing time limits within which development must occur from the date of the granting of the rezoning application.

Conclusions

In this section several land-use control policies have been investigated with the specific intent of analyzing each in terms of political, legal, social, economic, physical, aesthetic, and natural effects. By no means have the varied land-use control policies been covered exhaustively, but we have sought to touch the major areas of endeavors. We have sought to establish what rights in urban land the owner should possess. It has been implied that these rights have changed and will continue to change as pressures increase on man in his urban environment.

ALTERNATIVE FINANCIAL ARRANGEMENTS

In this section attention is focused on realistic courses of action which can be taken to finance the changes resulting from TOPAZ. Hopefully the various approaches examined would enable a decrease or redistribution of the present financial burden incurred by municipalities. While the majority represent more traditional revenue generating devices, the effort has also been to review innovative and seldom-used revenue sources. The emphasis is on forms which usually require local initiative; no attempt was made to address the broader concern of revamping the American public financing system. Similarly, while trying to be as comprehensive as possible, this work should not be viewed as exhaustive. Rather, it should be taken as a basic overview of the area of local and regional government revenue generation and development.

Local User Charges

As a source of revenue for city governments, service and user charges represent an increasingly significant factor. This fact stems in part from the basic service orientation assumed by local jurisdictions. The user charge itself is, of course, a charge for a good or service produced by the government, and is collected from the recipient of the service. As such, the charge aids in rationing the output among competing interests while assuring that the burden of payment is assumed by those who benefit in proportion to their consumption. This assists both the government and the citizenry in decisions related to the government's production of goods and services.

Traditionally, two principal categories of local public services have lent themselves to the imposition of user charges: (1) government services rendered directly to the public for their consumption; and (2) regulatory services. In the following paragraphs a brief description of each is made with appropriate notations.

Public Service Enterprises As mentioned above, the role of cities has historically focused on the delivery of public services. While many of these services possess a natural affinity for government operation, recent events have witnessed localities assuming functions which might otherwise have been deemed more appropriate for the private sector. Certainly today the position of public ownership of commercial type enterprises is a widely recognized and established practice.

Some of the public services now commonplace are: (1) utilities in general; (2) trash and refuse collection ; (3) parking; (4) public transportation; (5) special police services; (6) special fire services; (7) building plan checking; (8) engineering assistance; (9) street and curb repairs; (10) first aid and ambulance services; (11) hospital receiving services; (12) swimming pools; and (13) golf courses. While at first look many of these functions seem to represent considerable cash expenditures, they can in turn act as potential source of revenue.

A prevelant example of a public service operation is the water supply system. At the present time, three of four cities provide their citizens with water from publicly owned and operated systems. These revenues from such operations have for many years exceeded the concomitant expenses. It can be rightfully argued that many public services function under a deficit, though to a degree, this may be an intentional policy decision rendered to equalize greater community discrepancies. Public mass transit systems are a prime example of this where the total city gains in terms of the mobility of its citizens.

User Charges for Regulatory Services The second category of local government services amenable to charges are those which are regulatory in nature, usually operationalized in terms of permits and licenses. While these might not normally be associated with revenue generation, this area did account for over $2 billion in funds for cities in 1970.

Unquestionably, the complexity of contemporary society suggests a basic need for the regulation of conduct and practices. The costs so incurred by the municipalities represent a cost which most rightly should be borne by those directly involved. A sample of various types of permits and licenses shows a wide range of possibilities:

- Amusement and gaming devices
- Amusement places
- Alcoholic beverage license
- Attorney license
- Bicycle permit
- Cemetary license
- Electrician license
- Fire alarm device permit
- Food inspection permit
- Hawkers, peddlers, and similar salesman license
- Hotels, motels, rooming houses license
- Marriage license
- Motion picture license
- Motor fuel dealer's license
- Plumber's permit
- Restaurant and eating place license
- Vehicle permit
- Vending machine license

This list represents only a handful of the permits and licenses issued by local authorities.

The importance of such permits and licenses varies by jurisdiction, usually being a function of state law and local discretion. The use of the alcoholic beverage license, for instance, varies considerably from area to area. Generally the license will cover any combination of beer, wine, and liquor, and range from retail selling to sale by the drink. Moreover, the charges have been known to extend from $5 to $50 a day.

Real Property Taxation

When reference is made to the municipal revenue generating system, the general tendency is to think of the real property tax. Historically, the real property taxation has represented the major single source of revenue to the over 70,000 local governments authorized to impose it. While its relative percentage has been declining, real property taxes remain the largest single contributor to local budgets, accounting for 35 percent of the general revenues.

Recently, however, real property taxation has come under fire from several factions, including planners who claim that the present organizational mechanism for assessment and collection has distorted the urban landscape. Ostensibly, the tax works counter to larger planning objectives by encouraging development where undesired, and retarding development where it is most needed.

It is not the purpose of this section to examine the controversy surrounding real property taxes, nor to comment on recent attempts to use the tax as a land-use control mechanism. However, the point should be made that real property taxation does remain as a significant revenue input with expanding attempts made to utilize it for that purpose. Property taxes are flexible and are adaptable to local concerns and needs. What follows is a brief description of varied ways in which this tax has been molded to accomodate changing conditions. Again, in many instances the schemes focus on the regulation of development and land use though this should not preclude the viability of real property taxation as a revenue source.

Vacant Land Taxation Though the taxing of vacant land emphasizes issues of development, it is an alternative worthy of attention. In Taiwan, for example, land in developed urban areas which is not presently under productive utilization is subject to a tax ranging from 3 to 10 times the land value tax. The South Korean government has established a similar tax with the definition of unoccupied or vacant land being where structures cover no more than one-tenth of the total plot area. In a parallel move, Chilian localities impose a special tax on vacant land in developed areas which starts at 3 percent and increases yearly to a maximum of 6 percent.

Plan Conformity Taxation The development of plans for the patterning of urban areas has become commonplace in the contemporary world. This brings with it, of course, the concern for the ultimate implementation of the plans once conceived and written. To further this end, the French government levies a development tax, ranging up to 90 percent, on land not in conformity with the municipal general plan. Similarly, the state of Hawaii taxes property not according to existing land uses, as is usually the case, but rather with its conformity to the established planning objectives. While this is clearly an attempt to influence the direction of development, it is another taxing alternative.

Land Transfer Tax A more commonly employed system is the land transfer tax. Fundamentally, the tax is placed against the profit resulting from an exchange of land, that is, the difference between the value of the land at the time of the sale and the value at its acquisition. Its basic intent has been to discourage speculation by penalizing those who hold land briefly for the expressed purpose of capturing inflationary rises in property values.

In most instances the land transfer tax is a flat charge placed against the profit made on the land transaction. The rate varies from 1 percent in Afghanistan and Jordan to 7.4 percent in Spain. In Israel a progressive tax structure is employed with a level of taxation considerably greater. A charge of 20 percent is placed on profits which are less than twice the original cost; a 30 percent charge levied on profits 2 to 4 times the original cost; and a 40 percent charge on all remaining situations. Credit is given for the length of time the land is held in ownership, varying from 6 percent for 1 to 15 years, and 1 percent for over 15 years. No tax is imposed for land retained over 37 years.

Taxing Income from Real Property As an input resource, land is capable of generating an income even while it is being held. Accordingly, many governments levy a tax against income derived through the possession of land. In the British tax system, money earned from employment is termed "earned income" while income from real property is called "unearned income." The latter unearned income then becomes subject to taxation at a minimum rate of 40 percent.

Land Value Taxation The land value, or site value, tax is a levy imposed on the value of the land alone, irrespective of the value of the structures or absence thereof on the site. A popular derivation of this is the graded or differential tax which applies a higher rate of taxation to the land portion then to the improved portion of the property value. The city of Pittsburgh has been operating under such a system since 1914, taxing buildings and improvements at a rate only one half as high as that levied against the land value.

The arguments for the land value tax have been well formed, with considerable empirical evidence offered from its practice in Western Canada, Australia, New Zealand, and South Africa. Proponents suggest that it is an equitable tax as it focuses on the land's value, a factor which is in large measure a function of community, not individual, action such as community development and population growth. However, those concerned with development patterns are in favor of this tax as the decision of the land's use is not influenced by taxes. That is, the best and most profitable use prior to taxation remains the best use after the tax is imposed.

Special Assessment A fundmental issue of public finance is that of equity, or the proper allocation of the tax burden. Many experts suggest that the tax structure should be adjusted according to the benefits derived by the individual. In the field of property taxation this issue relates to the concern over special assessment. The special assessment process entails the singling out of particular properties for special taxation as a result of benefits accruing to them by virtue of near-by public works.

In Mexico City this system uses two forms of taxes. The first is the Planning Tax, which is a special assessment to cover project costs of opening, adjusting, or enlarging public ways, parks, gardens, and plazas. The assessment zone for parks, gardens, and plazas includes all property within 144 meters of the work, with the specific charge established through an "influence index." The second tax is termed the Cooperation Tax, which is levied against properties benefiting from water mains, sanitary sewers, storm sewers, sidewalks, street pavement, and lighting. Here the charge is levied only against properties fronting the improvement or having access to them. Rates vary according to the type of improvement installed and the quality of the improvement made. In circumstances where a pipeline may run down the center of a street, the charge is divided between each side of the roadway.

Assessment Procedures A basic problem surrounding property taxes is that of assessment. In even the most sophisticated tax systems there can be no guarantee that the assessed value properly reflects the property's actual worth. In part, to overcome this, Taiwan has established a rather unique system, called the Land Value Tax. Under this arrangement the assessment base for taxing unimproved land is the owner's self-declaration of its value. In other words, the property owner is responsible for the assessing or establishment of the market value of the property which in turn is used as the base for taxation. To assure that abuses are minimal, the government reserves the right to purchase the property at the price the owner sets. The selling is compulsory if the government decides it desires the lot at the owner's price.

Income Taxation

The use of income as a basis for taxation has been with us for some time. At the federal level, income taxes are the major source of revenue while increasingly the states are following in their footsteps. To date most local jurisdictions have been reluctant to impose such a tax. With their heavy reliance on property taxes, the levying of income taxes has been viewed as better left to higher levels of government. This attitude may very well be on the way out as new sources of revenue are sought.

The emphasis in this section will be on the two principal areas of income taxation: (1) corporate incomes; and (2) personal incomes.

Corporate Income Taxation

The experience of corporate income taxation by municipalities has been one of particular limitation. The few cities to have levied the tax include Baltimore, Detroit, Kansas City, St. Louis, and New York. In general, its application has been against net profits resulting from production conducted by the corporation within the city. Also, the rates have been low, flat charges, which in the two Missouri cities, for example, never extend beyond l-l/2 percent.

Personal Income Taxation The utilization of the personal income tax is slightly more widespread though there remains considerable leeway. At the present time, local personal income taxes are levied in 10 states, though in the majority of them it is used sparingly. In total, over 3500 local jurisdictions levy the tax. Its earliest local use in the United States was in Philadelphia in 1939. Eight years later the Pennsylvania legislature passed a wide-ranging authorization bill which permitted even the smallest jurisdiction in the state the power to collect personal income taxes. Presently, a large majority of the localities in that state use the tax as a revenue source.

The tax base for local personal income taxes generally consists of the gross earning of the individual. This includes all forms of income received as compensation for service, including salaries, wages, commissions, bonuses, incentive payments, and tips. Usually excluded are various types of unearned income in the form of dividends, interest, capital gains, pensions, annuities, and unemployment compensation. Seldom are allowances made for deductions or personal exemptions.

The rate structure in all cases is a simple low, flat, proportional rate. The majority range from a low of 0.25 percent in Wilmington, Delaware, to a high of 3.3125 percent in Philadelphia. In the case of Maryland jurisdiction, the local income tax rate is 20 to 50 percent of the state income tax.

In the application of the tax, problems do arise in regard to who and what income to tax. For example, some city residents are taxed only for income earned within the municipality while other jurisdictions tax the income regardless of its origin. Also, many cities tax non-residents for earnings received within the city limits. This latter situation can create conflicts when a resident of one community works in a neighboring city and is subject to dual taxation. Usually, however, the issue can be resolved by simply dividing the tax between the two jurisdictions so that the individual is not subject to an undue tax burden.

Consumption Taxes Second only to property taxation, consumption taxes represent a significant revenue generating source for local governments. The consumption tax is identified by being imposed on the transactions involving the purchase of goods and services where the impact is against the consumer in the purchasing price. For the purposes of this examination, consumption taxes refer to these types: (1) general sales tax; (2) selective sales (or excise tax); and (3) spendings tax.

General Sales Tax While selected cities have been using the general sales tax for some time, its widespread impact did not come until after World War II. In California, for example, in 1945 San Bernadino became the first city to impose the tax. Not long thereafter a whole host of cities in the state followed suit to tap this new revenue source. Today general sales taxes are used in 21 states and over 300 localities. In 1970, it was responsible for bringing in more than $2.5 billion in local funds.

The general sales tax operates on a flat rate, the local share ranging from a low of 0.5 percent to a high of 3 percent in 7 U.S. cities. Because of the flat rate system, there has been some opposition to its use. Opponents argue that the tax is in effect regressive, and does not reflect ability to pay and differentials in income groups. Proponents suggest, however, the tax has been a great benefit by releasing much of the pressure placed on property taxes. Also, they suggest that the tax assists in retrieving revenue from suburbanites who work and buy in the city.

Selective Sales Tax While the general sales tax is an across-the-board charge, selective sales taxes are aimed at singling out certain items or services for taxation. Ofttimes the tax may be above the general sales tax, making it in effect an excise tax. That distinction is not of direct concern to the present discussion, however. The following is an abbreviated list of some of the items commonly subject to selective sales taxation:

Motor fuel
Alcoholic beverages
Cigarettes and tobacco
Utilities
Admissions and amusements
Hotel occupancy
Gambling devices
Natural gas tax

Poll tax
Food tax
Airplane boarding fee
Motor vehicles

In the interest of space not all of these examples will be explored in detail. Instead, a number of the more commonplace ones will be reviewed.

Motor Fuel Tax As of a few years ago, over 300 municipalities and 36 counties levied a gasoline sales tax. Its largest administration has been in Alabama and New Mexico, where over 200 cities impose the tax. The charges range from 0.5 cent to 5 cents a gallon, though by far the poplar rate is 1 cent a gallon. There have been instances where overlapping local jurisdictions have each imposed the tax. This has been true especially in Alabama where both cities and counties levy the tax. The usual administrative procedure has the state collecting the city's tax in addition to the regular state gasoline tax and then channeling it back to the respective municipalities.

Alcoholic Beverages To date, the taxation of alcoholic beverages by local government occurs in only a few states. The city of New Orleans does levy a 40 cents a gallon tax on distilled spirits, 5 cents a gallon on light wines, and 10 cents a gallon on fortified wines, plus an excise of $1.50 a barrel on beer having an alcohol content of 6 percent or less. Similar examples include seashore resort cities in New Jersey which impose a retail sales tax on alcoholic beverages, while cities in West Virginia may impose a tax not to exceed the state tax on liquor sold in state stores. It should be noted that in some states, local governments impose a general sales tax on alcoholic beverages simply by including it in the base of these taxes. This is particularly common in localities where a general sales tax is already being used.

Cigarette and Tobacco Taxes The taxation of cigarettes and tobacco continues to grow in popularity with over 800 municipalities and counties using them. The two states with the largest number of localities using them are Alabama and Florida. In the latter, almost all incorporated municipalities impose this tax.

Usually the tax is a flat charge ranging between 1 and 3 cents levied against a standard package of cigarettes. In Evansville, Indiana, for example, the levying of a 2 cents a package cigarette tax plus monies from local businessmen raised enough revenue to construct a downtown mall for the mid-western city.

Overall Spendings Tax A revenue source which hasn't received much attention is the overall spending tax. The tax would be levied against total rather than specific expenditures and would be administered through personal reports such as net income tax. The rates would be graduated and personal exemptions could be accommodated. Proponents argue that services received by consumers can be easily included, involving less administrative difficulty than the retail sales tax. While this idea was first introduced in the early 1900's, it has never been implemented. The U.S. Senate Finance Committee did investigate its possibility during World War II, but it was never adopted.

Debt Management

In general, the normal operating expenses of local jurisdictions are met from the revenue retrieved from user charges, taxes, and intergovernmental payments. While deficits are always avoided, circumstances do not always allow this luxury. This concern becomes readily apparent when the need arises for the construction of physical facilities or the purchasing of land, which are high cost items usually paid off on a long term basis. When these instances arise, local jurisdictions rely on a number of debt management alternatives, including: (1) general obligation bonds; (2) revenue bonds; (3) municipal bond banks; (4) capital improvements program; (5) sinking funds; and (6) lease-purchase options.

General Obligation Bonds The most common technique used by municipalities for the assumption of long-term indebtedness is the issuance of general obligation bonds. Basically this bond establishes an obligation against all the taxable property in the city. A specific tax is then levied against this property which in turn is used to pay off the interest and principal. To control excesses, all states have statutory limitations on the amount of bonded indebtedness localities may assume. In the state of Virginia, local governments are allowed to issue bonds up to 18 percent of the total assessed value of the property in the locality. In Montgomery County, Virginia, for example, assessed value is 20 percent of the true market value. For the town of Blacksburg, with a population of 20,000, this means a debt limit of $1.9 million. Such a figure of course represents a limit and is not necessarily the actual indebtedness of the town.

Revenue Bonds In an effort to circumvent the debt limitations, cities will frequently utilize revenue bonds. Basically, the revenue bond uses exclusively the earnings from the specific project for which it was issued to pay off the interest and principal. In other words, the bonds are redeemed from the charges or tolls made on the facility and do not in turn represent an obligation against the general property of the city.

In some instances, it is incumbent that the jurisdiction present proof that a reasonable amount of revenue will be produced to retire the bonds on schedule. Since there is this risk, revenue bonds usually carry higher rates of interest. This should not, however, be viewed as a necessary deterrent to their use, as they have been used to finance numerous public facilities, including civic centers, toll bridges, golf courses, and water plants.

Municipal Bond Banks In an effort to deal more effectively with the question of municipal bonds, the states of New York and Vermont have each established what amounts to a municipal bond bank. Under the Vermont system, the Vermont Municipal Bond Bank assembles a group of local bond issues, then sells an issue of its own equal to the amount of the local issue, plus a sum for the reserve fund. Using the monies from its bonds, the bank buys the local bonds. As the town pays the bank off from tax revenue, the bonds are retired. While these bonds do not represent an obligation against the state of Vermont, the legislature can make up any deficiency in the debt reserve fund.

The New York state set-up is called the Urban Development Corporation (UDC) which is similar in intent to Vermont's but broader in scope. With the UDC, the general obligation bonds are paid off from the expected revenues in fees from office buildings, industrial parks, housing, and related projects. As with Vermont's system, a reserve fund exists to back up the bonds with the legislature permitted to make up deficits.

In short, the principal behind municipal bond banks is not so much to sell bonds that might not otherwise be marketable, but rather to sell them more easily and at a lower interest rate.

Capital Improvments Program Under this program, a locality plans for capital expenditures over a five to six year period. This first year is the budget year, in which all capital needs are funded for which money is available. The succeeding years contain information on projected needs for capital facilities and the status on current projects. This system would be difficult to use for the purchase of property due to the inability of most localities to predict accurately the need for certain types of land.

Sinking Fund A sinking fund could be used to establish a revolving fund for the purchase and development of land. While it may take a number of years to generate a fund sufficient for this purpose, this may be the only feasible alternative if only current funds are available and a bond issue cannot be supported.

Lease-Purchase Contracts The lease-purchase contract represents one of the most recent innovations in the field of public finance. Essentially this process allows the local jurisdiction to contract with any legal government authority for the construction of a facility according to plans they establish. In turn, the city leases it from the authority at a specific rate for a minimum number of years, with the option to purchase at a future date, according to the prearranged price. Municipalities have used this to contract with local school boards to construct school buildings and have then paid the board an annual rent which they use to pay off the debt. This allows the local jurisdiction to use general revenue for long term commitments.

In California, the counties operate under a lease-purchase system with two alternatives open to them. Under the first the county can contract with a local jurisdiction, or more commonly, the county or state retirement system, for the construction of a facility. The second plan allows them to form a private, non-profit corporation which may sell tax-exempt bonds secured by a lease with the county. This type of financing has been used for the Music Center in Los Angeles County and for the probation building in Orange County, California.

Intergovernmental Transfers

An increasingly important element in the revenue generating system for local governments is the intergovernmental transfer. The scope of this source should continue as is and may in all probability expand. For present purposes, intergovernmental transfers will be divided into three areas: (1) state transfers; (2) revenue sharing; and (3) federal grants.

State Tranfers The role of state monies in local governments is a generally known item. The major types of transfers from the state to localities consists of grants and shared taxes. Naturally the grant programs employ funds appropriated for particular purposes. While the programs vary from state to state, most cover the major areas of education, highways, and public welfare. Other grants from the states usually go beyond these basic concerns.

In the case of shared taxes, the assumption is made that the larger governmental authority is better equipped for the efficient collection of taxes which the lower authority gives up. In such an arrangement, the local government receives a portion of the tax yield collected for them by the state. This is frequently done with income taxes where smaller communities are hesitant about collecting a tax in which the state has already established a collection network. Again, the state would return the collected revenue to the appropriate local jurisdiction under such an operation.

Revenue Sharing One of the more uncertain money sources at the present time is revenue sharing. Ostensibly the causes behind the initiation of the revenue sharing program include:

1. The great proliferation of categorical grants has created exceedingly complex relationships between federal aid granters and state-local grantees and has tended to distort state and local program priorities.

2. The growing fiscal pressure on state and local treasuries has convinced the federal government of the need for increased federal aid and for relaxing of matching requirements.

3. Traditional approaches to grant-in-aid streamlining have failed.

Even with these programs as background, there remain some questions as to the final form the revenue sharing program will assume. As the Nixon administration has presented it, the overall structure will consist of a general revenue sharing and a special revenue sharing sector. The original proposal included $3.8 billion for general revenue sharing and $9.9 billion for special revenue sharing. Since the program was not fully implementable in 1972, only $2.3 billion was released.

The special revenue sharing program is of particular interest to the present discussion as it will mean the consolidation of most existing grants into the major areas of education, law enforcement, manpower, rural development, transportation, and urban development. A recent government publication notes that should the Better Communities Act of 1973 be passed, ". . .existing HUD programs would be replaced by special revenue sharing systems. . . ." The urban development sector of this new special revenue sharing program, for example, will be funded with monies taken from existing grants including Neighborhood Development Program, Code Enforcement, Demonstration Grants and Interim Assistance, Model Cities, Neighborhood Facilities, Water and Sewer Grants, Open Space and Historic Preservation, Rehabilitation Loans, and Public Facility Loans.

Each major funding area will have its own unique set of allocation factors designed to measure the relative need for the monies. It is also important to note that the special revenue sharing programs, unlike the traditional federal grants, will not require matching funds. Additionally, the maintenance of effort requirement will probably also be removed.

Federal Grants

The passing of federal monies directly to localities originated in the Depression of the 1930's with money handled by various ad hoc agencies such as the Works Progress Administration and Public Works Administration. In 1972, federal grants contributed $36.2 billion, which constitutes 16.7 percent of local government budgets. Needless to say, this makes it an important revenue source for local concern.

To delve into the details of eligibility and filing requirements is beyond the intended scope of this presentation. Rather this section will examine briefly a handful of grants presently available to present a sampling of grant possibilities.

Advance Acquisition of Land (Housing and Urban Development Act of 1965)

Under the provision of this grant, local communities are encouraged to acquire land in the advanced stages of planning to assure the orderly development of land and for the future availability of land for public purposes. These public purposes can include sewer and water lines, water treatment facilities, recreation centers, health facilities, airport, streets, and highways, rapid transit facilities, parks, and sanitary land fills. One example of its use is in Salt Lake County, Utah, where monies from this program were used for the acquisition of land to be used for detention pond facilities for flood control.

Acquisition and Development of Undeveloped Land (An Open Space Land Program--Title VII of the Housing Act of 1961, as Amended) The purpose of this grant is to provide local governments with funds for the acquisition and development of land for recreational, park, historic conservation, and scenic purposes. Up to 50 percent of the cost of acquisition is covered with further grants of up to 50 percent available for development programs. A recent grant of $47,206 to Quincy, Massachusetts, assisted them in purchasing nearly 50 acres of land known as Black Creek Land. Most of this area is a natural salt water marsh and will be preserved as a refuge for fish and waterfowl.

Outdoor Recreational Financial Assistance (Land and Water Conservation Fund Act of 1965) This program is designed to serve areas where concentration of people has resulted in the need for basic outdoor recreational facilities. Possible uses include multipurpose parks, ski areas, playgrounds, golf courses, swimming pools, hiking and bicycling paths, marinas, camping and picnicking areas, and hunting areas. The federal share is generally 50 percent except in certain economic redevelopment areas where it can go as high as 80 percent.

Public Works Planning Advances (Section 702, Housing Act of 1954) This program provides interest-free advances to enable the preparation of preliminary engineering and architectural designs and feasibility studies for specific public works. Included are most public works such as water and sewer systems, health facilities, and recreation programs. These advances are repayable without interest once construction is undertaken.

Public Facility Loans (Housing Amendment 1955, as Amended) This program provides long-term loans to finance the construction of needed public works. The loans are for up to 40 years and can cover 100 percent of the project's cost. Monies can be used for water and sewer facilities, gas distribution systems, street improvements, public buildings, and recreational facilities. The small southwestern town of Alamo, Texas (population 4000) has been the recipient of a number of such loans in the past few years, with one of $180,000 and another of $207,000. These have been used for street improvements, a drainage project, and the installation of new water and sewer facilities.

Basic Water and Sewer Facilities Grant (Section 702, Housing Act of 1965)
This grant affords assistance to local governments for the construction of basic water and sewer facilities which a community needs to assure and promote efficient and orderly growth. The federal government will pay 50 percent of the total project cost though assurance of the applicant's ability to finance the balance must be demonstrated. The money can be used toward almost any water or sewer related facility.

* * *

Other related grants available from the Federal government include:

Comprehensive Planning Grants
Historic Preservation Grants
Grants and Loans for Public Works and Development Facilities
Health Facilities Construction
Urban Parks
Land for Public Parks, Public Recreation Areas and Public Purposes
Park Planning--Technical Assistance and Training
Drainage Improvements
Water Pollution Control--Waste Treatment Works Construction
Solid Wastes--Technical Assistance and Training
Water Supply
Urban Mass Transportation
Traffic Operation Program for Increasing Capacity and Safety (TOPICS)
Neighborhood Facilities Grants
Water Resources Topographic Surveys and Investigations
Census Mapping and Statistical Reports
Census Special Tabulation and Services

SUMMARY

TOPAZ can be used to determine land use activity patterns in a given area. These activities must be carried on in a situation involving legal, political, physical, and financial constraints.

Two organizational arrangements may be used to replace uncoordinated and inefficient municipal departments. The local development agency and the local industrial development corporation, using TOPAZ, could do a much better job of promoting orderly growth and development.

Certain land use controls are necessary to promote orderly development, whether such development is planned by TOPAZ or by some other means. All those discussed previously are compatible with TOPAZ.

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Part V

SUMMARY OF RESEARCH PERFORMED, RESULTS, AND CONCLUSIONS

Research Performed

The main focus of the research reported here has been the derivation of land use patterns that minimize costs for water and sewer systems, using as an example the town of Blacksburg, Virginia. The technique employed to determine such patterns was TOPAZ (Technique for the Optimal Placement of Activities in Zones), an iterative mathematical programming procedure developed originally by Brotchie, Sharpe, and Toakley for use in Melbourne, Australia.

Basically, TOPAZ takes as inputs (1) the forecasted areawide total amount of land use activity in several categories (e.g., single family housing, industrial, and recreational); (2) the established amount of acres available for development in different zones in the study area; and (3) the per acre costs of establishing different services (e.g., water, sewer, local roads) for the different land uses in each zone. Then, as indicated above, TOPAZ allocates the future land uses to the available areas in each zone so as to minimize total service costs in the area (primarily water and sewer in this case). TOPAZ had been utilized previously in Blacksburg, Virginia and this was one of the main reasons why it was applied there again for this research. Data had been collected on capital costs for water and sewer, building construction, electric systems and local roads and streets. In addition, the submodel describing amenity benefits (land values) already had been calibrated and the transportation system (only highways in this case) had been coded. Blacksburg thus provided a convenient area for further explorations with TOPAZ since relatively little new data had to be collected.

Naturally the future cost for the different services had to be estimated using various models. Previous studies had focused almost exclusively on travel costs as obtained in part through the use of a "gravity" type model. Cost models for the other services were not nearly as sophisticated as this, and needed much improvement. In fact, when TOPAZ was employed previously in Blacksburg, the capital costs for water and sewer system improvements were obtained simply though discussion with local developers and real estate agents. As such, the costs were more "ball park" estimates rather than "scientifically" derived figures. One of the major purposes of this research thus was to develop improved models of water and sewer cost so that more accurate estimates could be made.

This modeling endeavor turned out to be a rather difficult task. Most engineers are used to being supplied with forecasts of future land use developments in various parts of an urban area and then determining the costs to serve that development. In this research it was necessary to develop a more general model that could be used to forecast water and sewer costs given any general land use pattern. This was done basically by (1) dividing Blacksburg into its natural watersheds, (2) comparing the demand to capacity for each existing link in the system in each watershed, (3) finding that alternative (from a preset list of alternatives) that would handle the excess demands, (4) determining the cost associated with the chosen alternative and allocating it among the different land use activities and zones. The procedure is a complicated one, but certainly gives much more reliable cost estimates than the "ball park" figures generated by the developers and real estate agents.

The modeling of water and sewer costs and their subsequent use in TOPAZ was only part of this research, however. On the theoretical side, an attempt has been made to find economic criteria, other than that of cost minimization, that could be used to define more precisely an economically efficient city. The other criteria investigated were: (1) net regional product, and (2) total consumers' surplus.

Neither of these criteria proved to be any more satisfying from a theoretical standpoint than cost minimization. Data for their measurement certainly would be more difficult to collect.

An attempt also was made to determine how costs for city services might be expected to vary with city size.

On a more applied level, an investigation was made of the mechanisms by which the land use patterns generated by TOPAZ might be implemented. The mechanisms studied fell into the categories of: (1) organizational structures (e.g., land development corporations); (2) land use controls (e.g., zoning); and (3) financing (e.g., revenue bonds). The legislation needed to augment these mechanisms also was discussed. Many do not require new legislation, and with the "quiet revolution" in land use controls taking place throughout the country, especially as a result of environmental concerns, it may be that many of the more radical controls discussed herein may become a reality in the not-too-distant future.

RESULTS

Both the results and conclusions from this research effort are divided into three groups, concerning:

1. Benefit criteria and city scale
2. Models of water and sewer costs and their use in TOPAZ
3. Alternative mechanisms for implementing TOPAZ results.

Benefit Criteria and City Scale

Cost minimization, the criterion used in TOPAZ, was the first one discussed in this part of the study. It was found that this criterion had several advantages. It was

1. quantifiable (and thus explicit),
2. relatively easy to find data for,
3. understandable to most people,
4. relatively easy to model, and
5. much discussed and evaluated in the literature.

Difficulties were found to be

1. no clear measure of benefits,
2. no consideration for "unquantifiables,"
3. failure to be exhaustive in identifying costs (e.g., capital costs for water and sewage treatment plants)
4. double counting of some costs (e.g., travel costs and amenity benefits),
5. possible improper choice of service lives and discount rates, and
6. no indication of incidence of costs (and thus of equity).

The use of consumers' surplus as a criterion provided at least one major advantage over cost minimization--a measure of benefit is stated. According to the theory of consumers' surplus, "net benefits" are the total of the differences between what people are willing to pay for specified goods or services and what they have to pay. The greater the differences, the more the net benefits. While having such a measure of benefit is a great advantage, many economists have found that consumers' surplus often is difficult to determine precisely. The user also must be willing to live with the following assumptions:

1. rational, economic man,
2. the existence of cardinal utilities,
3. the ability to measure utility in the market place,
4. the addition of utilities over groups of people,
5. at least one nonsubstitutable product,
6. perfect competition, and

7. constant marginal utility of money.

All other difficulties associated with the cost minimization criterion also hold.

The criterion of net regional product has some distinct advantages. Certainly a city would benefit greatly if it maintained a "trade surplus" in its relationship with the rest of the world. A sizable surplus would imply a large flow of goods and services to residents of the study area. The main problem with the determination of net regional (study area) product is that of data availability. Perhaps with a large scale collection effort, sufficient information could be obtained to measure the net product for a town such as Blacksburg. At present, however, no such data are available and the collection effort would be prohibitively expensive.

Because of the major difficulties with the concept and application of consumers' surplus and net regional product pointed out above, it was decided to keep cost minimization as the criterion for TOPAZ. Of interest for future studies, were the possible variations in costs as a function of city or regional size and density. A review of the literature led to the following results:

1. The lowest mean per capita annual expenditures (all purposes) for counties occurred for those in the 5000 to 100,000 population range.

2. The lowest per capita costs for infrastructure occurred in settlements in the 20,000 to 50,000 size range, with settlements of less than 5000 population having about 12 percent greater cost and those over 600,000 population having about 40 percent greater cost.

3. Municipal expenditures in the United States in fiscal year 1971 for highways, sewerage, and water supply did not vary significantly with population size. Expenditures for most other purposes, however, were found to be lowest in cities in the smallest population category (less than 50,000).

4. On a smaller scale, development and operating costs for blocks of eight story residences were 50 percent greater than for blocks of two story residences.

5. Also on a smaller scale, increases in standard housing densities by 25 percent decrease road development and journey costs by 2 to 4 percent, respectively.

In general it was also found from the literature that:

1. As the size of the suburban population increases, so also does the cost of city government.

2. The faster the rate of growth, the lower the per capita expenditure.

3. Neither "income" nor "percent of the population that is black" were explanatory of per capita government expenditures in cities.

Models of Water and Sewer Costs and Their Use in TOPAZ

There were two sets of trial applications of the water and sewer models in TOPAZ using the town of Blacksburg as an example. In the first set the rough estimates of water and sewer costs made by local developers and real estate agents were employed. Minimization of discounted annual costs was attempted for situations where:

1. All costs were considered.
2. Water and sewer system costs were neglected.
3. Sewer costs were neglected.
4. Water costs were neglected.

In these trials it was found that discounted water and sewer costs were about $200,000 each, yearly, and that the sum of the two comprised about 6 percent of the total cost of $6.9 million. Water and sewer costs thus appeared to be relatively insignificant, amounting to only about $10 per capita per year. It was not found, however, that great economies could be achieved by ignoring the water and sewer system and emphasizing other services. Total costs were reduced only $10,000 per year this way, which sum was only about $700 more than the increased cost of water and sewer.

Future land use patterns resulting from these four trials appeared to group in and around existing land uses. There were few differences in patterns between trials. Single family units tended toward close-in, vacant land where most services already were available. Apartments, townhouses, and mobile homes were located close to similar uses and existing commercial areas. Future commercial areas, parks, and schools were placed, as might be desired, in and among present and future residential areas.

Four additional trials were then made, this time using the water and sewer models developed as part of the project. These trials were of the same type as the previous four except no trial was run neglecting both water and sewer costs. Instead, an experiment was made where, for purposes of comparison, the maximization of total costs was derived.

The major findings in these trials were that:

1. The water and sewer cost models gave costs five to six times as great as the rough estimates of the developers and real estate agents. Costs for these services thus became as much as 25 percent of the total and amounted to about $55 per capita or $180 per household per year.

2. Despite the major changes in costs from the rough estimates, land use patterns were not altered to any great degree.

3. The maximum cost allocation, as expected, resulted in large holdings of all land uses being placed at selected zones on the periphery of the study area.

Alternative Mechanisms for Implementing TOPAZ Results

The organizational structures considered most advantageous for implementing TOPAZ results were local development corporations and agencies. The former, publicly-owned and non-profit corporations, were exemplified by the Philadelphia Industrial Development Corporation (PIDC). The PIDC has relatively great financial autonomy and has power to buy, sell, lease, and develop land and to issue bonds accordingly. The latter type of organizations are a consolidation of smaller governmental agencies, such as building inspection offices, zoning boards of appeal, and planning commissions. Local development agencies are capable of wielding many powers of land use control (as described below).

The various types of land use controls, including related taxation policies, considered relative to TOPAZ were:

1. mandatory dedication
2. eminent domain
3. preferential assessment
4. deferred taxation
5. European taxes such as:
    (a) taxes on capital gains and income from land

    (b) progressive taxes on property valuation increases

    (c) land increment taxes on the basis of eventual higher values of land

    (d) taxes on gross income from land with no allowance for depreciation, maintenance, or management costs.

6. easements
7. land banks
8. zoning
9. rezoning taxes
10. conditional rezoning

Mandatory dedication has been employed almost entirely to obtain school and park lands. Eminent domain cannot be used for public purchase of land without great justification and is often too expensive for a locality. Various tax and assessment schemes can be useful for forcing desired types of land use development but because of the complexity of the market, strategies may not be as successful as desired. Easements provide the benefits of reduced costs and maintenance of land in private hands. However, only very select (and small) pieces of land can be held in this manner. Land banks could have great potential but are expensive and would probably meet with great political resistance. Large tracts of land are difficult to assemble. Zoning, while useful, is more of a passive constraint mechanism than an active tool for land use development.

Funding sources available to a locality for achieving desired land use patterns include:

1. Local user charges
2. Real property taxation
3. Income taxation
4. Consumption taxation
5. Debt management
6. Intergovernmental transfers.

Most of these sources would prove to be undesirable politically, but changes as different as those resulting from TOPAZ probably would require significant funding, although the ultimate return on investment might prove significant.

CONCLUSIONS

Benefit Criteria and City Scale

1. Despite many apparent shortcomings, the criterion of minimization of total costs still appears to be best in conjunction with TOPAZ. It would have been desirable to explore alternative criteria in more detail, especially in terms of ease of data collection. Such was not possible in this small study, unfortunately, and we are not sure that economists have developed urban economy theory sufficiently to allow much further investigation of criteria anyway. On the positive side, however, many non-quantifiable factors can be taken into account in TOPAZ and tradeoffs made with cost figures. For example, available acreage in parts of zones felt to have some desirable (but intangible) environmental or social features would be restricted for growth, then the extra cost of services caused by such restrictions could be calculated and weighed against the intangible benefits.

2. Based on previous studies, which are not numerous, it appears that smaller cities and towns, such as Blacksburg, have an advantage in terms of low per capita costs for infrastructure and more generally for governmental services. Costs for highways, sewers, and water supply would not be expected to vary with population size that much, however. The major differences probably would occur in educational, welfare, health, police, and fire services and in travel.

Models of Water and Sewer Costs and Their Use in TOPAZ

1. It appears possible to develop reliable and accurate water and sewer models to be utilized in a situation, as with TOPAZ, where it is necessary to estimate costs based on any possible land use arrangement.

2. Water and sewer cost models of some sophistication are a definite need in conjunction with TOPAZ. Estimates made by local developers, real estate agents, and other people familiar with the study area may be in considerable error, probably because of misunderstanding of the objectives and needs of the study.

3. All allocations of land use in the tests were within and/or close to existing development. This demonstrates the overwhelming economies that accrue from agglomeration.

4. Costs for water and sewer services amount to about one-quarter of all costs accounted for in TOPAZ. The development of water and sewer systems thus is a sizable expense in overall development.

5. The difference between the lowest and highest costs for water and sewer services is not very great. Other costs, such as for travel, seem to vary more widely with allocation schemes.*

Alternative Mechanisms for Implementing TOPAZ Results

The organizational structures, land use controls, and financing mechanisms presently available to help implement land use patterns, such as those emerging from TOPAZ, all appear to be too highly fragmented, diverse, and weak to be sufficient except in unusual situations. What would be needed for such an endeavor would be a well-financed public or quasi-public planning organization with powers primarily over the housing and transporation sectors and most likely with almost complete ownership of land. Similar organizations exist in the United Kingdom, Sweden, and Australia. An organization with such characteristics is not very likely under present conditions in the United States, although there appears to be a gradual trend towards greater local government control, especially as some cities and counties try to retard or stop growth, primarily for environmental reasons.

Overall it appears that significant gains have been made in the quantitative methodology of TOPAZ. What seems to be needed now are applications in a variety of urban situations and greater analyses and real world experiments of implementation strategies.

*Note, however, that no trials were made to minimize or maximize only water plus sewer costs.

APPENDIX
Listing of TOPAZ Program

Reproduced on the following pages is a draft user's guide and a computer listing of the TOPAZ program as developed for and used in this research. If the reader is interested in utilization of TOPAZ, arrangements for a duplicate deck can be made by contacting the Virginia Water Resources Research Center.

```
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
      COMMON ESTCST(16,61,6),CC(61,61),TOTESC(16,61),ESTAB(16,61)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(112,2),DIST(61,61),CCC(18),ATTRCO(16),PRODCO(16)
      COMMON PR(61),AT(61),SA(61),TRIPS(61,61),BB(61,61),FTA(61,61)
      COMMON NQ,C2(16,61)
       COMMON COSTS(6,61),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION ENTRST(6),SERLIF(6)
      DIMENSION TITLE(20)
      REAL*8 TITLE
      INTEGER AA,ZZ,CCC
      INTEGER X,C,A,B,COST
C
C   TOPAZ PROGRAM BY J. W. DICKEY , VIRGINIA TECH , 1971
C
C   MAIN PURPOSE OF THE MAIN PROGRAM IS TO READ INPUTS , DO SOME PRELIMINARY
C   CALCULATIONS , AND CALL SUBROUTINES IN THE ITERATION PROCESS .
C
 1009 FORMAT(19X,2H* ,1X,16(I4,2X))
 1005 FORMAT(10X,110(1H*),/)
      WRITE(6,1002)
 1002 FORMAT(30X,'TOPAZ APPLICATION CONTROL PARAMETERS')
      READ(5,1000) M,NACTS,NECTCM,NL,NLOOP
 1000 FORMAT(5I4)
C
C   ENTRST(I)=THE INTEREST RATE ASSUMED FOR COST COMPONENT (I)
C   SERLIF(I)=THE EXPECTED LIFE OF COST COMPONENT (I)
```

```
C
      READ(5,1)(ENTRST(I),I=1,NECTCM)
      READ(5,2)(SERLIF(I),I=1,NECTCM)
    1 FORMAT(6F3.2)
    2 FORMAT(6F3.0)
      WRITE(6,1005)
       WRITE(6,1093) M,NACTS,NECTCM,NL,NLOOP
 1093 FORMAT(20X,'M=NUMBER OF ZONES =',I5,/,
     *20X,'NACTS= NUMBER OF ACTIVITY TYPES =',I3,/,
     *20X,'NECTCM= NUMBER OF COST COMPONENTS =',I3,/,
     *20X,'NL=NUMBER OF LINKS IN HIGHWAY NETWORK =',I3,/,
     *20X,'NLOOP=NUMBER OF ITERATIONS IN "TRNSPT" SUBROUTINE =',I3)
C
C   SET ITERATION LOOP COUNTERS
C
      NLP=1
      NQ=1
      WRITE(6,1005)
      WRITE(6,1008)
 1008 FORMAT(/,10X,'ZONE NO. ',2H* ,37X,'EXISTING ZONAL ACTIVITIES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
      DO 24 J=1,M
      READ(5,2000) (EXIST(I,J),I=1,NACTS)
 2000 FORMAT(5X,16F4.0)
   24 WRITE(6,1010) J,(EXIST(I,J),I=1,NACTS)
 1010 FORMAT(13X,I2,4X,2H* ,16(2X,F4.0))
      WRITE(6,1005)
```

```
      DO 508 K2=1,NECTCM
      DO 508 I=1,NACTS
      DO 507 J=1,M
  507 ESTCST(I,J,K2)=0.
  508 CONTINUE
C
C   READ TITLES (ON CARDS) FOR ESTABLISHMENT COST OR BENEFIT COMPONENTS
C
      DO 10 K2=2,NECTCM
      READ(5,2571) (TITLE(K5),K5=1,10)
 2571 FORMAT(10A8)
      WRITE(6,2572) (TITLE(K5),K5=1,10)
 2572 FORMAT(//,' ZONE ',2H* ,25X,10A8)
      WRITE(6,1995)
 1995 FORMAT(120(1H*),/)
      WRITE(6,1999)(I,I=1,14)
 1999 FORMAT(6X,2H* ,14(I5,3X))
      WRITE(6,1995)
C
C FORMAT FIXUP FOR COST INPUTS
C   IN THIS PARTICULAR APPLICATION , ZONES 15, 21, 24, 25, 35, 42, AND 44 -49
C   WERE NOT USED IN TOPAZ BUT WERE IN OTHER ANALYSES . THUS THEY HAD TO BE
C   SKIPPED HERE .
C
      IF(K2.GT.2) GO TO 504
      DO 503 I=1,11
  503 READ(5,8990) (ESTCST(I,J,K2),J=1,14),(ESTCST(I,J,K2),J=16,20),
     1             (ESTCST(I,J,K2),J=22,23),(ESTCST(I,J,K2),J=26,34),
     1             (ESTCST(I,J,K2),J=36,41), ESTCST(I,43,K2),
```

```
     1               (ESTCST(I,J,K2),J=50,61)
 8990 FORMAT(6(5X,9F7.0,/))
      GO TO 735
  504 DO 505 I=1,6
  505 READ(5,8990) (ESTCST(I,J,K2),J=1,14),(ESTCST(I,J,K2),J=16,20),
     1               (ESTCST(I,J,K2),J=22,23),(ESTCST(I,J,K2),J=26,34),
     1               (ESTCST(I,J,K2),J=36,41), ESTCST(I,43,K2),
     1               (ESTCST(I,J,K2),J=50,61)
C
C    IN THIS APPLICATION THE ESTABLISHMENT COSTS FOR ACTIVITIES 7 TO 11 ARE THE
C    SAME IN EACH ZONE AS FOR ACTIVITY 6 .
C
      DO 501 J=1,M
      DO 500 I=7,11
  500 ESTCST(I,J,K2)=ESTCST(6,J,K2)
  501 CONTINUE
  735 DO 622 J=1,M
      WRITE(6,9000)J,(ESTCST(I,J,K2),I=1,14)
 9000 FORMAT(2X,I2,2X,2H* ,14(' ',F7.0))
  622 CONTINUE
      WRITE(6,1995)
   10 CONTINUE
C
C    CALCULATE THE CAPITAL RECOVERY FACTOR, RPIN(K2), FOR COST COMPONENT(K2) AT
C    AN INTEREST RATE OF ENTRST(K2) AND A SERVICE LIFE OF SERLIF(K2)
C
      DO 9990 K2=1,NECTCM
      RPIN(K2)=ENTRST(K2)*((1.+ENTRST(K2))**SERLIF(K2))/((1.+ENTRST(K2))
     1**SERLIF(K2)-1.)
```

```
      DO 9990 I=1,NACTS
      DO 9990 J=1,M
 9990 ESTCST(I,J,K2)=ESTCST(I,J,K2)*RPIN(K2)
      CALL ALCATE
      WRITE(6,2004)
 2004 FORMAT(50X,'LINK INFORMATION')
      WRITE(6,1995)
      WRITE(6,2005)
 2005 FORMAT(14X,'LINK NUMBER',23X,'LENGTH OF LINKS (MILES)',16X,'AVERAG
     *E SPEED (MILES/HOUR)')
      WRITE(6,1995)
      DO 1530 JI=1,NL
      READ(5,2006)(DLINK(JI,KI),KI=1,2)
 2006 FORMAT(19X,F3.1,F4.0)
C
C   LINK LENGTH DATA INPUTTED IN INCHES ON 800 SCALE MAP . THE 0.1575 FACTOR
C   CONVERTS THESE INCHES TO MILES .
C
      DLINK(JI,1)=DLINK(JI,1)*.1515
      WRITE(6,2007) JI,(DLINK(JI,KI),KI=1,2)
 2007 FORMAT(18X,I3,34X,F7.5,34X,F3.0)
 1530 CONTINUE
      WRITE(6,1995)
C
C   FOR THOSE ZONES NOT INCLUDED IN THE TOPAZ , THE INTERZONAL DISTANCES AND
C   TRAVEL TIMES HAVE ARBITRARILY BEEN SET = 9.999 AND 8.888 RESPECTIVELY .
C   ANY POSITIVE VALUES ARE ACCEPTABLE HERE , AND THEY ARE NOT ACTUALLY
C   RECOGNIZED IN TOPAZ (ZEROS WOULD MESS UP GRAVITY MODEL)
C
```

```
      DO 5324 AA=1,M
      DO 5323 ZZ=1,M
      DIST(AA,ZZ)=9.999
 5323 FTA(AA,ZZ)=8.888
 5324 CONTINUE
      DO 4001 KJ=1,1488
C
C     FOR EACH ZONAL PAIR , THE MINIMUM TIME PATH HAS BEEN IDENTIFIED BEFOREHAND .
C     THE CCC(JJ)'S ARE THE LINK NUMBERS ON EACH MINIMUM PATH . KEEP ZONE PAIRS
C     DATA IN ORDER , E.G., 1-1, 1-2, ........., 61-61
C
      READ(5,4003) AA,ZZ,(CCC(JJ),JJ=1,18)
 4003 FORMAT(4X,I3,I3,18I3)
      FTAT=0.0
C
C     COMPUTATION OF MINIMUM TIME PATHS AND CORRESPONDING DISTANCES .
C
      ADIST=0
      DO 4111 JJ=1,18
      IF(CCC(JJ).EQ.0)GO TO 4111
      JKLM=CCC(JJ)
      IF(DLINK(JKLM,2).LE.1.) GO TO 4111
      FTAT=FTAT+DLINK(JKLM,1)*60./DLINK(JKLM,2)
      ADIST=ADIST+DLINK(JKLM,1)
 4111 CONTINUE
      FTA(AA,ZZ)=FTAT
      DIST(AA,ZZ)=ADIST
 4001 CONTINUE
      DO 7501 LN=1,61
```

```
      DO 7501 LK=LN,61
      DIST(LK,LN)=DIST(LN,LK)
      FTA(LK,LN)=FTA(LN,LK)
 7501 CONTINUE
 7002 FORMAT(' FROM',2H* )
 7003 FORMAT(2X,'TO',2X,2H* ,I3,15I6)
      WRITE(6,7001)
 7001 FORMAT(44X,'DISTANCE BETWEEN ZONES IN MILES')
      WRITE(6,1995)
      WRITE(6,7003)(KKK,KKK=1,16)
      WRITE(6,1995)
      WRITE(6,7002)
      WRITE(6,1995)
      DO 8311 NOL=1,61
      WRITE(6,7004) NOL,(DIST(NOL,MOL),MOL=1,16)
 7004 FORMAT(2X,I2,1X,2H* ,16(F5.3,1X))
 8311 CONTINUE
      WRITE(6,1995)
      WRITE(6,7001)
      WRITE(6,1995)
      WRITE(6,7003)(KKK,KKK=17,32)
      WRITE(6,1995)
      WRITE(6,7002)
      WRITE(6,1995)
      DO 8312 NNN=1,61
      WRITE(6,7004) NNN,(DIST(NNN,MOL),MOL=17,32)
 8312 CONTINUE
      WRITE(6,1995)
      WRITE(6,7001)
```

```
      WRITE(6,1995)
      WRITE(6,7003)(KKK,KKK=33,48)
      WRITE(6,1995)
      WRITE(6,7002)
      WRITE(6,1995)
      DO 8313 MMM=1,61
      WRITE(6,7004) MMM,(DIST(MMM,MOL),MOL=33,48)
 8313 CONTINUE
      WRITE(6,1995)
      WRITE(6,7001)
      WRITE(6,1995)
      WRITE(6,7003)(KKK,KKK=49,61)
      WRITE(6,1995)
      WRITE(6,7002)
      WRITE(6,1995)
      DO 8314 LLL=1,61
      WRITE(6,7004) LLL,(DIST(LLL,MOL),MOL=49,61)
 8314 CONTINUE
      WRITE(6,1995)
      WRITE(6,2520)
 2520 FORMAT(//,20X,'LAND USE TRIP PRODUCTION AND ATTRACTION COEFFICIENT
     1S  (TRIPS / DAY / ACRE)')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
      READ(5,2525)(PRODCO(I),I=1,NACTS)
 2525 FORMAT(16F4.1)
      WRITE(6,9040)(PRODCO(I),I=1,NACTS)
 9040 FORMAT(10X,'PRODCO',6X,16F6.1)
```

```
      READ(5,2525)(ATTRCO(I),I=1,NACTS)
      WRITE(6,9045)(ATTRCO(I),I=1,NACTS)
 9045 FORMAT(10X,'ATTRCO',6X,16F6.1)
      WRITE(6,1005)
C
C     ADDITION OF ALL ESTABLISHMENT UNIT COMPONENT COSTS AND BENEFITS (IN MILLIONS
C     OF $) .
C
      DO 100 I=1,NACTS
      DO 100 J=1,M
      TOTESC(I,J)=0.
      DO 99 K2=1,NECTCM
   99 TOTESC(I,J)=TOTESC(I,J)+ESTCST(I,J,K2)/1000000.
  100 CONTINUE
C
C     CHECK TO SEE IF ANY INTERZONAL TRAVEL TIME HAS BEEN INADVERTENTLY SET TO
C     ZERO (WHICH WOULD MESS UP GRAVITY MODEL) .
C
      KK=0
      DO 805 J=1,M
      DO 804 K=J,M
      IF(FTA(J,K).LE.0.001) GO TO 3737
      GO TO 804
 3737 WRITE(6,3747) J,K
 3747 FORMAT('  FTA ZERO CHECK  ',2X,I5,I5)
  804 CONTINUE
  805 CONTINUE
C
C     START OF ITERATIONS USING TRNSPT (TRANSPORTATION PROBLEM) . INITIAL SOLUTION
```

```
C   IS "COSTED" FIRST .
C
  150 CALL AMNITY(NLP)
      CALL ESTIM(NLP)
      CALL SUMMRY
      DO 820 J=1,M
      DO 820 I=1,NACTS
C
C   NOTE: THE C(I,J)'S SHOULD BE SCALED UP SO AS TO BE VERY LARGE SINCE THEY ARE
C   INTEGERS IN SUBROUTINE TRNSPT . (COSTS LESS THAN 1 ARE ROUNDED OFF) .
C
C   IF DESIRE IS TO MAXIMIZE , THEN USE  820 C(I,J)=-C2(I,J)*1000000 .
C
  820 C(I,J)=C2(I,J)*1000000.
      INF=2147483646
      CALL TRNSPT(NACTS,M,INF,16,61)
      DO 600 I=1,NACTS
      DO 600 J=1,M
  600 ACTS(I,J)=X(I,J)
      IF(NLP.EQ.NLOOP) GO TO 50
      NLP=NLP+1
      GO TO 150
   50 STOP
      END
      SUBROUTINE ALCATE
C
C   THIS SUBROUTINE READS IN OR CALCULATES THE AMOUNT OF EACH ACTIVITY
C   TO BE ALLOCATED AND THE AMOUNT OF LAND AVAILABLE FOR DEVELOPMENT.
C   A(I) = FUTURE AMOUNT OF ACTIVITY (I) TO BE ALLOCATED.
```

```
C     PINCR = POPULATION INCREASE
C     RATIO(I) = PERCENTAGE OF POPULATION INCREASE THAT WILL DEMAND
C     HOUSING TYPE (I)
C     APU(I) = ACRES/UNIT OF HOUSING TYPE (I).
C     PPU(I) = PEOPLE/UNIT OF HOUSING TYPE (I).
C
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
      COMMON ESTCST(16,61,6),CC(61,61),TOTESC(16,61),ESTAB(16,61)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(112,2),DIST(61,61),CCC(18),ATTRCO(16),PRODCO(16)
      COMMON PR(61),AT(61),SA(61),TRIPS(61,61),BB(61,61),FTA(61,61)
      COMMON NQ,C2(16,61)
       COMMON COSTS(6,61),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      INTEGER A,VACNT,B
 1005 FORMAT(10X,110(1H*),/)
 1009 FORMAT(19X,2H* ,1X,16(I4,2X))
      WRITE(6,1012)
 1012 FORMAT(/,40X,'AMOUNT OF FUTURE ACTIVITIES OF EACH TYPE TO BE ALLOC
     *ATED')
      WRITE(6,1005)
      READ(5,2001)(A(I),I=6,NACTS)
 2001 FORMAT(25X,11I4)
      READ(5,2000)PINCR
 2000 FORMAT(F7.0)
      DO 2003 I=1,5
      A(I)=0.0
 2003 READ(5,2002)RATIO(I),PPU(I),APU(I)
```

```
 2002 FORMAT(F7.4,F5.2,F5.2)
      DO 2999 I=1,5
 2999 A(I)=PINCR*RATIO(I)/PPU(I)*APU(I)
C
C    MAKE SURE THAT THE FUTURE AMOUNT OF ACRES ALLOCATED ARE EQUAL TO THE
C    EXISTING AMOUNT OF UNDEVELOPED LAND BY ADJUSTING A(16),THE FUTURE
C    ACRES OF UNDEVELOPED LAND, IF IT IS NECESSARY.
C    VACNT AND ISUM ARE DUMMY VARIABLES USED FOR ACCUMULATING EXISTING
C    ACRES OF UNDEVELOPED LAND AND FUTURE ALLOCATIONS OF ACTIVITIES
C    1 -15,RESPECTIVELY..
C
      VACNT=0
      DO 2004 J=1,M
 2004 VACNT=VACNT+EXIST(16,J)
      ISUM=0
      DO 2005 I=1,15
 2005 ISUM=ISUM+A(I)
      A(16)=VACNT-ISUM
      WRITE(6,1016) (A(I),I=1,NACTS)
1016  FORMAT(20X,'A(1)=FUTURE ACRES OF SINGLE FAMILY UNITS =',I8,/,
     *20X,'A(2)=FUTURE ACRES OF APARTMENTS =',I8,/,
     *20X,'A(3)=FUTURE ACRES OF TOWNHOUSES =',I8,/,
     *20X,'A(4)=FUTURE ACRES OF PLANNED UNIT DEVELOPMENT =',I8,/,
     *20X,'A(5)=FUTURE ACRES OF MOBILE HOMES =',I8,/,
     *20X,'A(6)=FUTURE ACRES OF CONVENIENCE COMMERCIAL =',I8,/,
     *20X,'A(7)=FUTURE ACRES OF REGIONAL COMMERCIAL =',I8,/,
     *20X,'A(8)=FUTURE ACRES OF NEIGHBORHOOD PARKS =',I8,/,
     *20X,'A(9)=FUTURE ACRES OF TOWN PARKS =',I8,/,
     *20X,'A(10)=FUTURE ACRES OF PRIMARY SCHOOLS =',I8,/,
```

```
     *20X,'A(11)=FUTURE ACRES OF SECONDARY SCHOOLS =',I8,/,
     *20X,'A(12)=FUTURE ACRES OF PUBLIC AND SEMIPUBLIC LAND =',I8,/,
     *20X,'A(13)=FUTURE ACRES OF INDUSTRY =',I8,/,
     *20X,'A(14)=FUTURE ACRES OF STREETS =',I8/,
     *20X,'A(15)=FUTURE ACRES OF UNIVERSITY =',I8,/,
     *20X,'A(16)=FUTURE ACRES OF UNDEVELOPED LAND =',I8)
      WRITE(6,1005)
      WRITE(6,1025)
 1025 FORMAT(/,40X,'ACRES OF LAND AVAILABLE FOR DEVELOPMENT IN EACH ZONE
     *')
      WRITE(6,1005)
      WRITE(6,1026)
 1026 FORMAT(20X,'ZONE NO. ',18X,'ACRES')
      WRITE(6,1005)
      DO 70 J=1,M
C
C    IN ALL ZONES THE AMOUNT OF LAND PRESENTLY VACANT IS SET EQUAL TO THAT
C    AVAILABLE FOR FUTURE DEVELOPMENT . THIS MAY NOT ALWAYS BE DESIRABLE .
C    REMEMBER THAT SUM A(I) MUST = SUM B(J).
C
      B(J)=EXIST(16,J)
   70 WRITE(6,1028) J,B(J)
 1028 FORMAT(24X,I2,15X,I10)
      WRITE(6,1005)
      WRITE(6,1029)
 1029 FORMAT(/,10X,'ZONE NO. ',10X,'INITIAL ALLOCATIONS - FUTURE ACTIVIT
     *IES TO ZONES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
```

```
      WRITE(6,1005)
      DO 73  J=1,M
   73 READ(5,1031)(ACTS(I,J),I=1,NACTS)
 1031 FORMAT(5X,16F4.0)
C
C    STATEMENT NUMBERS FROM 1034 TO 1038 CHECK TO SEE IF THE CORRECT
C    AMOUNT OF EACH ACTIVITY HAS BEEN ALLOCATED IN THE INITIAL SOLUTION.
C    IF THE INITIAL SOLUTION IS INCORRECT, ADJUSTMENTS ARE MADE TO
C    CORRECT IT.
C    ITACT = DUMMY VARIABLE USED TO ACCUMULATE THE ACRES OF A PARTICULAR
C    ACTIVITY (I) THAT HAS BEEN ALLOCATED TO ALL 61 ZONES.
C    ICHNG = DIFFERENCE BETWEEN THE TOTAL AMOUNT OF AN ACTIVITY THAT MUST
C    BE ALLOCATED,A(I), AND THE AMOUNT THAT HAS ACTUALLY BEEN ALLOCATED
C    TO THE ZONES,ITACT.
C
C    IF DESIRED THE PROGRAM WILL GENERATE AN INITIAL SOLUTION IF THE FOLLOWING
C    STATEMENTS ARE INSERTED AT THIS POINT IN THE PROGRAM.
C                 DO 5000 J=1,M
C                 DO 5000 I=1,15
C                 ACTS(16,J)=ACTS(16,J)+ACTS(I,J)
C            5000 ACTS(I,J)=0.0
C
 1034 DO 1033 I=1,NACTS
      ITACT=0
      DO 1032 J=1,M
 1032 ITACT=ITACT+ACTS(I,J)
      ICHNG=A(I)-ITACT
      IF(I.NE.16)GO TO 1043
      IF(ICHNG.EQ.0)GO TO 1043
```

```
      WRITE(6,1040)
C
C    'FLAG - ALLOCATION PROBLEM' INDICATES THAT THERE IS AN INCONSISTENCY
C    BETWEEN THE TOTAL AMOUNT TO BE ALLOCATED, A(I), AND THE TOTAL AMOUNT
C    THAT WAS ACTUALLY ALLOCATED,ACTS(I,J), IN THE ADJUSTED INITIAL
C    SOLUTION.
C
 1040 FORMAT(/,10X,' FLAG-ALLOCATION PROBLEM')
      GO TO 74
 1043 IF(ICHNG)1037,1033,1035
 1033 CONTINUE
      GO TO 74
 1035 DO 1036 J=1,M
      IF(ACTS(16,J).LT.ICHNG)GO TO 1039
      ACTS(I,J)=ACTS(I,J)+ICHNG
      ACTS(16,J)=ACTS(16,J)-ICHNG
      GO TO 1034
 1039 ACTS(I,J)=ACTS(I,J)+ACTS(16,J)
      ICHNG=ICHNG-ACTS(16,J)
      ACTS(16,J)=0.0
 1036 CONTINUE
      GO TO 1034
 1037 DO 1038 J=1,M
      IF(ACTS(I,J).LT.IABS(ICHNG))GO TO 1041
      ACTS(I,J)=ACTS(I,J)+ICHNG
      ACTS(16,J)=ACTS(16,J)-ICHNG
      GO TO 1034
 1041 ICHNG=ICHNG+ACTS(I,J)
      ACTS(16,J)=ACTS(16,J)+ACTS(I,J)
```

```
      ACTS(I,J)=0.0
 1038 CONTINUE
   74 DO 72 J=1,M
   72 WRITE(6,1010) J,(ACTS(I,J),I=1,NACTS)
 1010 FORMAT(13X,I2,4X,2H* ,16(2X,F4.0))
      WRITE(6,1005)
      RETURN
      END
      SUBROUTINE AMNITY(NLP)
C
C   THIS SUBROUTINE DETERMINES THE AMENITY BENEFIT COST COMPONENT FOR EACH ZONE.
C   FOR THIS COMPONENT, WHICH IS BASED ON ASSESSED LAND VALUE, THE COST OR
C   BENEFIT IS THE SAME FOR ALL ACTIVITIES IN A PARTICULAR ZONE.
C   NLP=ITERATION OR LOOP COUNTER
C   Z(K,J)=THE VALUE OF REGRESSION EQUATION VARIABLE K IN ZONE J.
C    Z(1,J)=INVERSE OF DISTANCE FROM CBD(ZONE 50) TO ZONE J.
C    Z(2,J)=PROPORTION OF LAND IN ZONE J ALLOCATED TO COMMERCIAL ACTIVITIES.
C    Z(3,J)=PROPORTION OF ZONE J ALLOCATED FOR MULTI-FAMILY HOUSING
C    Z(4,J)=PROPORTION OF ZONE J ALLOCATED FOR SINGLE FAMILY HOUSING.
C    Z(5,J)=FUTURE POPULATION DENSITY(PEOPLE/ACRE) IN ZONE J.
C   USE(I,J)=EXISTING + FUTURE AMOUNT OF ACTIVITY I ALLOCATED TO ZONE J.
C   TOTLND(J)=TOTAL AMOUNT OF LAND(ACRES) IN ZONE J.
C   CONSTN=CONSTANT IN THE LAND VALUE REGRESSION EQUATION.
C   POP(J)=EXISTING POPULATION IN ZONE J.
C   APOP(J)=FUTURE POPULATION IN ZONE J.
C   DIST(J,50)=DISTANCE FROM ZONE J TO THE CBD(ZONE 50).
C
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
      COMMON ESTCST(16,61,6),CC(61,51),TOTESC(16,61),ESTAB(16,61)
```

```
      COMMON M,NACTS,NECTCM,NL,NLCOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(112,2),DIST(61,61),CCC(18),ATTRCO(16),PRODCO(16)
      COMMON PR(61),AT(61),SA(61),TRIPS(61,61),BB(61,61),FTA(61,61)
      COMMON NQ,C2(16,61)
       COMMON COSTS(6,61),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION Z(5,61),USE(16,61),TOTLND(61),COEF(5),VALUE(61),POP(61),
     1APOP(61)
 1005 FORMAT(10X,110(1H*),/)
      DO 3020 K=1,5
      DO 3020 J=1,M
 3020 Z(K,J)=0.0
      DO 3002 I=1,NACTS
      DO 3002 J=1,M
 3002 USE(I,J)=EXIST(I,J)
      IF(NLP.NE.1)GO TO 3011
 3006 DO 3000 J=1,M
      TOTLND(J)=0.0
      DO 3000 I=1,NACTS
 3000 TOTLND(J)=TOTLND(J)+EXIST(I,J)
 3008 READ(5,3009)CONSTN,(COEF(K),K=1,5)
      READ(5,3010)(POP(J),J=1,M)
 3009 FORMAT(6F10.2)
 3010 FORMAT(15F5.0)
C
C     CALCULATE THE ESTIMATED FUTURE POPULATION IN ZONE J. THE CALCULATION IS
C     BASED ON THE EXISTING POPULATION AND THE ALLOCATION OF FUTURE HOUSING
C     ACTIVITIES TO ZONE J.
```

```
C
 3011 DO 3012 J=1,M
      APOP(J)=POP(J)
      DO 3012 I=1,5
 3012 APOP(J)=APOP(J)+ACTS(I,J)*PPU(I)/APU(I)
      DO 3013 I=1,NACTS
      DO 3013 J=1,M
 3013 USE(I,J)=USE(I,J)+ACTS(I,J)
C
C   DETERMINE THE VALUE OF EACH REGRESSION EQUATION VARIABLE FOR ZONE J.
C
 3007 DO 3001 J=1,M
      IF(EXIST(16,J).EQ.0.)GO TO 3001
      Z(1,J)=1./DIST(J,50)
      Z(2,J)=(USE(6,J)+USE(7,J))/TOTLND(J)
      Z(3,J)=(USF(2,J)+USE(3,J)+USE(5,J))/TOTLND(J)
      Z(4,J)=USE(1,J)/TOTLND(J)
      Z(5,J)=APOP(J)/TOTLND(J)
 3001 CONTINUE
C
C   CALCULATE THE LAND VALUE OR AMENITY BENEFIT IN EACH ZONE.
C
      DO 3003 J=1,M
      VALUE(J)=0.0
      IF(EXIST(16,J).EQ.0.)GO TO 3003
      VALUE(J)=CONSTN
      DO 3004 K=1,5
 3004 VALUE(J)=VALUE(J)+COEF(K)*Z(K,J)
C
```

```
C    IF THE LAND VALUE IS LESS THAN 0 IT IS SET EQUAL TO 0.
C
       IF(VALUE(J).LT.0.)VALUE(J)=0.
C
C    LAND VALUATIONS IN THIS CASE WERE ASSESSED AT 20% OF MARKET VALUE SO THIS
C    CONVERSION WAS NECESSARY. ALSO SINCE THEY ARE A NEGATIVE COST COMPONENT,
C    THE LAND VALUES OR AMENITY BENEFITS ARE GIVEN A NEGATIVE VALUE.
C
      VALUE(J)=-VALUE(J)/.20
 3003 CONTINUE
      WRITE(6,1005)
      WRITE(6,1025)
 1025 FORMAT(/,40X,'AMENITY BENEFITS (LAND VALUES)')
      WRITE(6,1005)
      WRITE(6,1026)
 1026 FORMAT(20X,'ZONE NO. ',18X,'$/ACRE')
      WRITE(6,1005)
      DO 1029 J=1,M
 1029 WRITE(6,1028)J,VALUE(J)
 1028 FORMAT(24X,I2,15X,F10.0)
      WRITE(6,1005)
      DO 3005 I=1,11
      DO 3005 J=1,M
 3005 ESTCST(I,J,1)=VALUE(J)*RPIN(1)
      DO 3014 I=1,NACTS
      DO 3014 J=1,M
      TOTESC(I,J)=0.0
      DO 3015 K2=1,NECTCM
 3015 TOTESC(I,J)=TOTESC(I,J)+ESTCST(I,J,K2)/1000000.
```

```
 3014 CONTINUE
      WRITE(6,5227)
 5227 FORMAT(//,' ZONE ',2H* ,40X,'ALL COSTS - BENEFITS  ($M/ACRE)')
      WRITE(6,1995)
 1995 FORMAT(120(1H*),/)
      WRITE(6,1999)(I,I=1,14)
 1999 FORMAT(6X,2H* ,14(I5,3X))
      WRITE(6,1995)
      DO 515 J=1,M
  515 WRITE(6,9162) J,(TOTESC(I,J),I=1,14)
 9162 FORMAT(2X,I2,2X,2H* ,14(1X,F7.6))
      WRITE(6,1995)
      RETURN
      END
      SUBROUTINE FSTIM(NLP)
C
C    THIS SUBROUTINE "COSTS OUT" ALLOCATIONS (INCLUDING USE OF GRAVITY MODEL) AND
C    SETS UP ARTIFICIAL COST COEFFICIENTS FOR THE TRNSPT SUBROUTINE .
C
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
      COMMON FSTCST(16,61,6),CC(61,61),TOTESC(16,61),ESTAB(16,61)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(112,2),DIST(61,61),CCC(18),ATTRCO(16),PRODCO(16)
      COMMON PR(61),AT(61),SA(61),TRIPS(61,61),BB(61,61),FTA(61,61)
      COMMON NQ,C2(16,61)
       COMMON COSTS(6,61),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
C
```

```
C     ELIMINATION OF VACANT LAND (LAST ACTIVITY NUMBER) IN CALCULATIONS .
C
      NACMUL=NACTS-1
C
C     START CALCULATIONS FOR GRAVITY MODEL .
C
      DO 922 J=1,M
      SA(J)=0.
      AT(J)=0.
      PR(J)=0.
      DO 922 I=1,NACMUL
      PR(J)=PR(J)+PRODCO(I)*(ACTS(I,J)+EXIST(I,J))
  922 AT(J)=AT(J)+ATTRCO(I)*(ACTS(I,J)+EXIST(I,J))
      DO 9999 J=1,61
      DO 9999 L=1,61
      SA(J)=SA(J)+AT(L)*(1.)/(FTA(J,L)**2.)
 9999 CONTINUE
C
C     CC(J,K) IS PARTIAL CONTRIBUTION OF GRAVITY MODEL TO TRNSPT COST COEFFICIENT
C
      DO 940 J=1,M
      DO 940 K=1,M
      CC(J,K)=0.0
  940 CONTINUE
      DO 8999 J=1,61
      DO 8999 K=1,61
      CC(J,K)=AT(K)*((1.)/(FTA(J,K)**2.))/SA(J)
 8999 CONTINUE
C
```

```
C    CHECK TO INSURE THAT IF NO EXISTING ACTIVITY (INCLUDING VACANT) AT ALL IN
C    ZONE , NO COST OF TRAVEL TO OR FROM THAT ZONE IS CALCULATED .
C
      DO 88 J=1,M
      DO 88 K=J,M
      BLAH1=0.
      BLAH2=0.
      DO 80 I=1,NACTS
      BLAH1=BLAH1+EXIST(I,J)
   80 BLAH2=BLAH2+EXIST(I,K)
      BB(J,K)=0.
      IF(BLAH1.EQ.0.) GO TO 88
      IF(BLAH2.EQ.0.) GO TO 88
C
C    CALCULATION OF TRAVEL COST ($ MILLIONS) . IS ASSUMED HERE THAT EACH DAILY
C    PERSON TRIP FROM GRAVITY MODEL WILL BE REPEATED 200 TIMES A YEAR.
C
      BB(J,K)=DIST(J,K)*0.065*200./1000000.
   88 BB(K,J)=BB(J,K)
      DO 950 I=1,NACTS
C
C    CALCULATION OF ARTIFICIAL COST FOR TRNSPT SUBROUTINE .
C
      DO 950 J=1,M
      C2(I,J)=0.
C
C    IF TRAVEL COST IS NOT TO BE CONSIDERED , ELIMINATE NEXT FOUR STATEMENTS AND
C    CHANGE STATEMENT 950 TO READ: 950 C2(I,J)=C2(I,J)+TOTESC(I,J) . ONLY NEED
C    TWO ITERATIONS OF TRNSPT (NLOOP=2) UNDER THESE CIRCUMSTANCES .
```

```
C
      SUM=0.
      DO 949 K=1,M
  949 SUM=SUM+BB(J,K)*CC(J,K)*PRODCO(I)
      SUM=SUM+TOTESC(I,J)
  950 C2(I,J)=C2(I,J)+SUM
      S2=0.
C
C    CALCULATION OF INTERZONAL PERSON TRIPS , TOTAL TRIPS , AND TOTAL TRAVEL COST
C
      T=0.
      DO 926 J=1,M
      DO 926 K=1,M
      TRIPS(J,K)=0.0
      TRIPS(J,K)=PR(J)*AT(K)*((1.)/(FTA(J,K)**2.))/SA(J)
  555 T=T+TRIPS(J,K)
      S2=S2+TRIPS(J,K)*BB(J,K)
  926 CONTINUE
C
C    CALCULATION OF TOTAL ESTABLISHMENT COMPONENT COSTS AND TOTAL OVERALL COST OF
C    SOLUTION ($ MILLIONS) .
C
      DO 704 K2=1,NECTCM
      TOTCCT(K2)=0.
      DO 704 J=1,M
      COSTS(K2,J)=0.
      DO 705 I=1,NACTS
  705 COSTS(K2,J)=COSTS(K2,J)+ACTS(I,J)*ESTCST(I,J,K2)
  704 CONTINUE
```

```
      DO 706 K2=1,NECTCM
      DO 706  J=1,M
  706 TOTCCT(K2)=TOTCCT(K2)+COSTS(K2,J)
      T2=0.
      DO 707  K2=1,NECTCM
  707 T2=T2+TOTCCT(K2)/1000000.
      G=T2+S2
      RETURN
      END
      SUBROUTINE  SUMMRY
C
C   THIS SUBROUTINE IS FOR PRINTING OUT RESULTS OF CALCULATIONS WITH RESPECT TO
C   EACH SOLUTION . INTERZONAL TRIPS ARE PRINTED ONLY FOR INITIAL AND LAST
C   SOLUTION .
C
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
      COMMON ESTCST(16,61,6),CC(61,61),TOTESC(16,61),ESTAB(16,61)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(112,2),DIST(61,61),CCC(18),ATTRCO(16),PRODCO(16)
      COMMON PR(61),AT(61),SA(61),TRIPS(61,61),BB(61,61),FTA(61,61)
      COMMON NQ,C2(16,61)
       COMMON  COSTS(6,61),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
 1005 FORMAT(10X,110(1H*),/)
 1009 FORMAT(19X,2H* ,1X,16(I4,2X))
 1010 FORMAT(13X,I2,4X,2H* ,16(2X,F4.0))
      WRITE(6,9007) NQ
 9007 FORMAT(//////,10X,'DESIGN LOOP',I5,////////)
```

```
      WRITE(6,3505)
 3505 FORMAT(//,40X,'TOTAL COSTS - BENEFITS  ($M)')
      WRITE(6,1005)
      WRITE(6,3510) T2,S2,G
 3510 FORMAT(30X,'TOTAL ESTABLISHMENT COSTS - BENEFITS =',F16.4,/,
     *30X,      '                    TOTAL TRAVEL COSTS =',F16.4,/,
     *30X,      '             SUM TOTAL COSTS - BENEFITS =',F16.4)
      WRITE(6,1005)
      WRITE(6,3712)
 3712 FORMAT(//,19X,2H* ,10X,'COMPONENT COSTS AND BENEFITS IN EACH ZONE
     * ($)')
      WRITE(6,1005)
      WRITE(6,3713)
 3713 FORMAT(10X,'ZONE NO. ',2H* ,6X,'BENEFITS',2X,'BUILD.UNIT',2X,'WATE
     *R',5X,'SEWER',5X,'STREETS',4X,'ELECTRIC')
      WRITE(6,1005)
      DO 372 J=1,M
  372 WRITE(6,3714) J,(COSTS(K2,J),K2=1,NECTCM)
 3714 FORMAT(13X,I2,10X,6F10.0)
      WRITE(6,1005)
      WRITE(6,3715)(TOTCCT(K2),K2=1,NECTCM)
 3715 FORMAT(10X,'TOTALS',9X,6F10.0)
      WRITE(6,1005)
      WRITE(6,3515)
 3515 FORMAT(//,10X,'ZONE NO. ',2H* ,10X,'ALLOCATIONS OF FUTURE ACTIVITI
     *ES TO ZONES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
```

```
      DO 20 J=1,M
   20 WRITE(6,1010) J,(ACTS(I,J),I=1,NACTS)
      WRITE(6,1005)
      IF(NQ.EQ.1) GO TO 50
      IF(NQ.NE.NLOOP) GO TO 51
   50 WRITE(6,3520)
 3520 FORMAT(//,20X, 'FUTURE DAILY INTERZONAL TRIPS')
      WRITE(6,1005)
      WRITE(6,3525)(K,K=1,10)
 3525 FORMAT((10X,'ZONE NO.',2X,1H*,10I10))
      WRITE(6,1005)
      DO 940 J=1,M
  940 WRITE(6,3530) J,(TRIPS(J,K),K=1,10)
 3530 FORMAT((10X,I2,8X,1H*,10F10.0))
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=1,10)
 3540 FORMAT((/,10X,'TRIP ATTRS',1H*,10F10.0))
      WRITE(6,3535) (PR(K),K=1,10)
 3535 FORMAT((10X,'TRIP PRODS',1H*,10F10.0))
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525)(K,K=11,20)
      WRITE(6,1005)
      DO 941 J=1,M
  941 WRITE(6,3530) J,(TRIPS(J,K),K=11,20)
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=11,20)
      WRITE(6,3535) (PR(K),K=11,20)
```

```
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525)(K,K=21,30)
      WRITE(6,1005)
      DO 942 J=1,M
  942 WRITE(6,3530) J,(TRIPS(J,K),K=21,30)
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=21,30)
      WRITE(6,3535) (PR(K),K=21,30)
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525)(K,K=31,40)
      WRITE(6,1005)
      DO 943 J=1,M
  943 WRITE(6,3530) J,(TRIPS(J,K),K=31,40)
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=31,40)
      WRITE(6,3535) (PR(K),K=31,40)
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525)(K,K=41,50)
      WRITE(6,1005)
      DO 944 J=1,M
  944 WRITE(6,3530) J,(TRIPS(J,K),K=41,50)
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=41,50)
```

```
      WRITE(6,3535) (PR(K),K=41,50)
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525)(K,K=51,60)
      WRITE(6,1005)
      DO 945 J=1,M
  945 WRITE(6,3530) J,(TRIPS(J,K),K=51,60)
      WRITE(6,1005)
      WRITE(6,3540) (AT(K),K=51,60)
      WRITE(6,3535) (PR(K),K=51,60)
      WRITE(6,1005)
      WRITE(6,3520)
      WRITE(6,1005)
      WRITE(6,3525) M
      WRITE(6,1005)
      DO 946 J=1,M
  946 WRITE(6,3530) J,TRIPS(J,61)
      WRITE(6,1005)
      WRITE(6,3540) AT(61)
      WRITE(6,3535) PR(61)
      WRITE(6,1005)
      WRITE(6,3545) T
 3545 FORMAT(///,10X,'TOTAL NUMBER OF TRIPS =',F10.0)
   51 NQ=NQ+1
      RETURN
      END
      SUBROUTINE TRNSPT(M,N,INF,M1,N1)
      COMMON ACTS(16,61),EXIST(16,61),A(16),B(61),C(16,61),X(16,61)
```

```
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION V(62),XSJ(62),S(62),R(62),
     *LISTV(62),U(62),XIS(62),D(62),G(62),LISTU(62),XB(62,62)
      INTEGER COST,C,X,A,B
      INTEGER P,H,Y,T,V,XSJ,S,R,LISTV,U,XIS,D,G,LISTU
      LOGICAL XB
C
C     THE PARAMETERS ARE C(I,J) - ARRAY OF COSTS
C                        A(I)   - QUANTITIES AVAILABLE
C                        B(J)   - QUANTITIES REQUIRED
C                        I=1,....M , J=1,....N
C     SUM OF A(I) = SUM OF B(J)
C     - INF - HAS TO BE THE GREATEST +VE INTEGER WITHIN MACHINE CAPACITY
C     ALL QUANTITIES HAVE TO BE INTEGER
C     THE FLOWS * X(I,J) * ARE COMPUTED BY THE  PRIME-DUAL-ALGORITHM
C     CITED IN  HADLEY,G.  LINEAR PROGRAMMING , READING,LONDON, 1962.
C     THE PROCEDURE FOLLOWS THE DESCRIPTION GIVEN ON P357.
C     MULTIPLE SOLUTIONS ARE LEFT OUT OF ACCOUNT.
C
C     ARRAY - XB(I,J) - FOR NOTATION OF  CIRCLED CELLS.
C     - LISTU(I) - AND - LISTV(J) - LISTS OF LABELED ROWS AND COLUMNS
C     OTHER NOTATIONS FOLLOW HADLEY.
C
C
      DO 10 I=1,M
   10 XIS(I)=A(I)
      DO 20 J=1,N
   20 XSJ(J)=B(J)
      DO 70 I=1,M
```

```
      H=INF
      DO 30 J=1,N
      X(I,J)=0
      P=C(I,J)
      IF (P.LT.H) H=P
   30 CONTINUE
      U(I)=H
      DO 60 J=1,N
      IF (C(I,J).EQ.H) GO TO 40
      GO TO 50
   40 XB(I,J)=.TRUE.
      GOTO 60
   50 XB(I,J)=.FALSE.
   60 CONTINUE
   70 CONTINUE
      DO 120 J=1,N
      H=INF
      DO 100 I=1,M
      IF (XB(I,J)) GO TO 80
      GO TO 90
   80 V(J)=0
      GOTO 120
   90 D(I)=C(I,J)-U(I)
      P=C(I,J)-U(I)
      IF (P.LT.H) H=P
  100 CONTINUE
      V(J)=H
      DO 110 I=1,M
      IF (D(I).EQ.H) XB(I,J)=.TRUE.
```

```
110 CONTINUE
120 CONTINUE
    DO 130 J=1,N
130 LISTV(J)=0
    DO 140 I=1,M
140 LISTU(I)=0
150 DO 210 I=1,M
    DO 200 J=1,N
    IF (XB(I,J)) GO TO 160
    GO TO 200
160 IF (XSJ(J).LE.XIS(I)) GO TO 170
    GO TO 180
170 H=XSJ(J)
    X(I,J)=XSJ(J)
    GOTO 190
180 H=XIS(I)
    X(I,J)=XIS(I)
190 XSJ(J)=XSJ(J)-H
    XIS(I)=XIS(I)-H
200 CONTINUE
210 CONTINUE
220 ISUM=0
    DO 221 J=1,N
221 ISUM=ISUM+XSJ(J)
    IF (ISUM.EQ.0) GOTO 610
    DO 230 J=1,N
    R(J)=0
230 S(J)=0
    H=0
```

```
      K=1
  240 DO 300 I=1,M
      IF (XIS(I).GT.0) GO TO 250
      GO TO 290
  250 D(I)=XIS(I)
      G(I)=2*N
      DO 280 J=1,N
      IF (XB(I,J).AND.R(J).EQ.0) GO TO 260
      GO TO 280
  260 S(J)=D(I)
      R(J)=I
      LISTV(K)=J
      K=K+1
      IF (XSJ(J).GT.H) GO TO 270
      GO TO 280
  270 H=XSJ(J)
      P=J
  280 CONTINUE
      GOTO 300
  290 D(I)=0
      G(I)=0
  300 CONTINUE
  310 IF (K.EQ.1) GOTO 440
      L=1
      DO 370 K=1,N
      J=LISTV(K)
      LISTV(K)=0
      IF (J.EQ.0) GOTO 380
      DO 360 I=1,M
```

```
      IF (XB(I,J).AND.X(I,J).GT.0.AND.G(I).EQ.0) GO TO 320
      GO TO 360
  320 IF (X(I,J).LE.S(J)) GO TO 330
      GO TO 340
  330 D(I)=X(I,J)
      GOTO 350
  340 D(I)=S(J)
  350 G(I)=J
      LISTU(L)=I
      L=L+1
  360 CONTINUE
  370 CONTINUE
  380 IF (L.EQ.1) GOTO 440
      K=1
      DO 420 L=1,M
      I=LISTU(L)
      LISTU(L)=0
      IF (I.EQ.0) GOTO 430
      DO 410 J=1,N
      IF (XB(I,J).AND.R(J).EQ.0) GO TO 390
      GO TO 410
  390 S(J)=D(I)
      R(J)=I
      LISTV(K)=J
      K=K+1
      IF (XSJ(J).GT.H) GO TO 400
      GO TO 410
  400 H=XSJ(J)
      P=J
```

```
  410 CONTINUE
  420 CONTINUE
  430 GOTO 310
C
C     END OF LABELING PROCESS
C
  440 IF (H.GT.0) GO TO 490
      GO TO 460
  460 ISUM=0
      DO 461 J=1,N
  461 ISUM=ISUM+XSJ(J)
      IF (ISUM.EQ.0) GO TO 610
      GO TO 530
  490 K=P
      IF (S(K).LT.XSJ(K)) GO TO 500
      GO TO 510
  500 H=S(K)
      GOTO 520
  510 H=XSJ(K)
  520 Y=R(K)
      X(Y,K)=X(Y,K )+H
      XIS(Y)=XIS(Y)-H
      XSJ(K)=XSJ(K)-H
      T=G(Y)
      IF (T.EQ.2*N) GOTO 220
      X(Y,T)=X(Y,T)-H
      XIS(Y)=XIS(Y)+H
      XSJ(T)=XSJ(T)+H
      K=T
```

```
      GOTO 520
  530 H=INF
      DO 560 I=1,M
      DO 550 J=1,N
      IF (G(I).NE.0.AND.R(J).EQ.0) GO TO 540
      GO TO 550
  540 P=C(I,J)-U(I)-V(J)
      IF (P.LT.H) H=P
  550 CONTINUE
  560 CONTINUE
      DO 570 I=1,M
      IF (G(I).NE.0) U(I)=U(I)+H
  570 CONTINUE
      DO 580 J=1,N
      IF (R(J).NE.0) V(J)=V(J)-H
  580 CONTINUE
      DO 600 I=1,M
      DO 590 J=1,N
      IF(C(I,J).NE.U(I)+V(J)) GO TO 590
      XB(I,J)=.TRUE.
  590 CONTINUE
  600 CONTINUE
      GO TO 220
  610 COST=0
      DO 620 I=1,M
  620 COST=COST+A(I)*U(I)
      DO 630 J=1,N
  630 COST=COST+B(J)*V(J)
      RETURN
```

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