DIRECTING THE EVOLUTION OF URBAN LAND USE TO ACHIEVE IMPROVED TRANSPORTATION SYSTEM PERFORMANCE

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This paper investigates the potential for directing the growth of an urban region so that the evolving urban form contributes to high levels of access opportunity with minimum travel requirements. Measures of total travel, accessibility, and spatial equity are defined for use in the evaluation of alternative urban spatial patterns. A computer-aided investigation determines optimum locations within the urban region for expected growth. Repeated application of a technique for assigning small increments of growth results in the definition of a high-performance growth path for a 10- to 20-year period. As a case study, the population and employment growth forecast for 1970 to 1990 for the Puget Sound region in the state of Washington is assigned to subregions. Contrast of the study results with current growth trends reveals that new travel requirements could be reduced by two-thirds, access levels could be improved 4 times, and distributional equity could be improved 3 times. These results are judged to be significant enough to warrant further intensive investigation into the feasibility and desirability of actually trying to achieve an urban form that could produce such dramatic improvements in transportation system performance without further substantial investments in capital-intensive transportation facilities or highly subsidized transportation services.

•DEMAND for travel occurs because of the desires of the residents of an urban region to participate in activities that are dispersed in space. The transportation problem can be defined as the need to provide access to these activities. Until recent years, when the environmental crisis began to teach us that social problems cannot be dealt with in isolation from one another, it seemed reasonable to approach the transportation problems of cities by increasing mobility, that is, by making it easier to travel through the construction and operation of transportation facility systems. Today, however, we are more aware that the attempt to solve a problem in one area may cause even more serious problems in other areas. Thus new freeways in urban regions can of themselves generate enough new traffic so that resulting congestion cancels any desired gains in mobility. In addition, freeways cause social disruption when stable neighborhoods must be destroyed to make room for the new facilities, ever-increasing numbers of automobiles pollute the air, and, more recently, fuel shortages have reminded us again that our traditional methods of solving transportation problems have built-in pitfalls that can leave us in a final state that is worse than the one in which we began. Awareness of these additional problems has called increasing attention to alternatives to the construction of new transportation facilities.

This report is based on an investigation of the underlying causes of travel. The chosen perspective is that travel demand is a derived demand; that is, travel is not an economic good desired for itself only. The economic good offered by a transportation system is accessibility or access opportunity. The focus of this paper is on the access opportunity resulting from the spatial pattern of land use, called the urban form, together with an associated transportation system. The underlying hypothesis is that different urban forms have different transportation requirements or that different urban forms differ in their abilities to satisfy accessibility-related goals. The idea that urban form and transportation are interrelated is not new. In fact, one of the principal motivations behind the comprehensive land use and transportation planning efforts of the 1960s was to take advantage of the knowledge of this relationship to devise plans for the guidance of urban growth into efficient forms with the most economical transportation system requirements. However, because of the complexity of the problem, these efforts were not entirely successful, and a systematic investigation of the travel requirements of various urban forms has not yet taken place.

The objective of this study was to determine ways in which an urban region might be encouraged to grow so that improved access opportunity results without the need for construction of new transportation facilities. If growth could be channeled in such a way that increased demand for travel did not result, then new transportation facilities would not have to be constructed. Such a planning concept could be termed a nontransportation solution for the transportation problem. This approach appears desirable because it promises to reduce future levels of adverse environmental impacts that result from transportation facility systems and because, if we do not spend money on expensive new transportation facilities, then conceivably the funds could be available to make cities more livable.

Specifically, the study developed the means for determining when and where growth should occur within an urban region so that access opportunity increased to the maximum extent possible while any increases in travel requirements were minimized. These 2 criteria (opportunity and economic efficiency) are commonly applied in the evaluation of plans; in recent years, a third criterion, equity, also has increased in importance. That is, if a service is provided socially, we must consider the distributional effects of the manner in which the service is provided. Because accessibility (the service provided by a transportation system) is a quantity that is distributed spatially, determining whether subareas of an urban region have good or poor accessibility is possible. An index of deprivation that measures those areas suffering from low accessibility levels can be devised, and this index can provide an indication of how well a particular urban form-transport system performs from an equity standpoint. Hence 3 measures of performance were defined. They correspond to opportunity, efficiency, and equity goals. Growth strategies also were developed so that these performance measures were maximally improved.

PREVIOUS STUDIES OF URBAN FORM AND PERFORMANCE

The decade of the 1960s witnessed the beginning of large-scale, systematic land use and transportation planning efforts. As documented by Boyce, Day, and McDonald (1), a prevalent assumption among planners at the beginning of this time was that different land use arrangements did have different transportation requirements. The hope was that substantial transport cost savings could be realized if more efficient urban forms could be discovered. Accordingly, a major goal of these projects was to investigate several alternative urban forms and to evaluate these alternatives in terms of their transportation system requirements. Although many alternatives were tested, a major finding in the evaluation of Boyce, Day, and McDonald (1) was that the transport requirements did not vary a great deal from one land use alternative to another. Thus, in general, the planning efforts failed to find any alternative that was substantially better than the others.

The planning efforts of the 1960s represent the first major attempt to integrate land use and transportation planning, but the emphasis of the efforts was not on the use of urban form to reduce travel requirements. Instead, it was on modal balance. The expectation was that the urban form that allowed the greatest balance between highway and transit modes would perform more efficiently than a form that depended highly on a single mode of transport.

One major land use and transportation study not included in the critique of Boyce, Day, and McDonald (1) was carried out by Hansen and Morrison (2) for the city of Canberra, Australia. This study adopted a relatively simple modeling environment to prepare and evaluate alternative plans easily. Furthermore, a very large growth increment was simulated so that major differences in the alternatives could appear. Alternatives were developed for a time period in which Canberra's population was expected to increase 10-fold, which could take 50 to 100 years. Eight major alternatives were evaluated, and a major conclusion of the study was that great potential exists for guiding the long-term development of spatial arrangements of activities in ways that will minimize the travel requirements of the urban region. Average lengths of trips varied by up to 15 percent under varying conditions of population and employment densities and varying concentrations of activities either in linear patterns or concentrically about the major regional center.

Using a hypothetical city and an even simpler modeling framework than that of Hansen and Morrison, Hemmens (3) also was able to identify significant variation in the transportation requirements of various urban forms. Two critiques of the Hemmens experiment offered by Beck (5) and Schneider and Beck (6) are noted here. The first is Hemmens' use of a linear programming formulation to simulate travel behavior, and the second is the selection of a relatively small number of alternatives for detailed study out of what is a large combinatorial space.

More recently, Edwards and Schofer (4) have investigated the energy requirements of the travel patterns associated with various hypothetical urban forms. This study used a Lowry-type model to realistically describe the urban system, but, like the Hemmens study, it did not attempt to find an optimal spatial structure. Instead, it enumerated some of the characteristics of urban forms with high and low energy intensiveness. In general, the authors found that forms with relatively spread-out population and employment, congestion in the transport network, and high dependence on the automobile mode required greater energy for transportation.

To examine as wide a range of alternatives as possible, Beck (5) and Schneider and Beck (6) devised a technique for describing the population and employment configuration of an urban region as a point in a combinatorial space. They then experimented with a search algorithm for finding optimal configurations. Their search heuristic is particularly well suited for finding an optimum when several different criteria for optimality are to be considered. They were able to explore trade-offs among such goals as minimizing total travel, maximizing accessibility, and reducing loads on the transportation network. The major weakness of their search technique is that it can be applied economically only to very simple descriptions of an urban region. This limitation results from the extreme rapidity with which the size of the combinatorial space grows with increasingly complex descriptions of the urban system.

The studies just mentioned had in common the goal of identifying the characteristics of an optimum urban form. The technique adopted in this study attempts instead to add new growth to an existing urban form in such a way that overall system performance improves to the maximum extent possible. Population and employment growth are repeatedly added to zones in small quantities. A growth strategy is thus defined, and, over a long period of time, a high-performance urban spatial structure will result gradually. The technique of incrementally maximizing changes in performance measures provides a sort of exploratory calculation the results of which may provide a basis for improved policy decisions.

The following section develops the incremental maximizing methodology. The technique of describing alternative urban forms as points in a combinatorial space will provide the basis for the experiments described here. In a major departure from Beck's and Schneider and Beck's work, the combinatorial search procedure has been abandoned because providing results that can be applied with reasonable confidence to an actual large and complex urban region is desired. This objective leads at once to the necessity of searching extremely large combinatorial spaces, which is beyond the capability of the previously described search heuristic approach. The technique adopted involves calculating a gradient, or direction to move, in the combinatorial space to obtain the greatest improvement in some criterion for optimality.

METHODOLOGY

The problem of interest is to determine an urban growth strategy that gradually results in an urban form that contributes to the solution of transportation problems. The technique consists of determining the locations within the urban region where the next small increments of population and employment growth should be located. When these increments are added in, the urban form changes slightly. Performance of the system is evaluated, and then the process is repeated. The method consists of 3 main parts. The first part of the methodology is selection of a model for describing the urban system. The urban region is divided into zones, and levels of population and employment are assigned to each zone. The transportation system is represented by a network consisting of nodes (1 for each zone) and links connecting the nodes. A gravity model is used to simulate journey-to-work travel in the region. The second part of the methodology is the selection of criteria for the evaluation of performance of the urban system. Three criteria were chosen for the current study: opportunity, efficiency, and equity. The third part of the methodology is the development of a technique that uses 1 of the performance criteria to determine a location for the addition of new growth so that the criterion is maximally enhanced. This technique consists of calculating the rate of change, that is, the gradient, of the performance measure when the growth increment is allowed to occur anywhere within the region. The decision of where to add the increment is made on the basis of obtaining maximum improvement in the performance measure.

The Gravity Model

The gravity model is written in a form suggested by Wilson (7).

$$T_{ij} = A_i B_j O_i D_j F(c_{ij}) \quad (1)$$

where

T_{ij} = number of trips between zone i and zone j,
A_i = balancing factor,
B_j = balancing factor,
O_i = number of trip origins in zone i,
D_j = number of trip destinations in zone j,
$F(c_{ij})$ = distance decay function or friction factor, and
c_{ij} = generalized cost of traveling from zone i to zone j.

$$A_i = \left[\sum_j B_j D_j F(c_{ij})\right]^{-1} \quad (2)$$

$$B_j = \left[\sum_i A_i O_i F(c_{ij})\right]^{-1} \quad (3)$$

Calculating the trip distribution matrix $[T_{ij}]$ essentially requires solving for $[A_i]$ and $[B_j]$ by an iterative procedure. The form of the distance decay function used in the current study is

$$F(c_{ij}) = \exp(-\beta c_{ij}) \quad (4)$$

where β is the distance decay exponential factor.

The major assumptions of the current study are that

1. Population and jobs are homogeneous, i.e., all people are equally attracted to all job opportunities and all people value travel time equally;
2. The transportation system can be considered to consist of only 1 mode;
3. People's consideration of cost of travel can be explained totally by the time required to make a trip;
4. Consideration of only the journey to work is adequate for evaluating the performance of the urban form and its transport system, that is, the only important access opportunity is accessibility to employment, and efficiency and equity are of importance to only this category of trip making; and
5. All transportation systems characteristics and user behavior characteristics will remain constant in time.

Performance Measures

Performance measures provide one way of summarizing aggregate behavior of the urban system. They are calculated as mathematical functions of the variables used to describe the urban form and the travel characteristics obtained from the gravity model. The measures permit comparison of various urban forms and various growth strategies. Because one alternative generally will not be superior in terms of all evaluation criteria used, trade-offs among goals and the relative importance of the various evaluation criteria must be determined. No attempt will be made in the current study to weight the criteria or to determine a single, best-growth strategy. Instead, the performance criteria will be considered one at a time, and trade-offs that occur will be noted.

The first criterion, opportunity, is measured by an accessibility index. The gravity model distance decay function provides a reasonable measure of accessibility. The index is constructed by multiplying the number of opportunities at each destination zone by the friction factor and then summing over all destination zones. If this index is then summed for all people in the region, an aggregate measure of total system access opportunity is obtained. This measure is called total weighted accessibility (TWACC) and is defined

$$TWACC = \sum_i O_i \sum_j DF(c_{ij}) \tag{5}$$

The second criterion is that travel requirements be minimized; therefore, the appropriate measure is the total travel (TTRAV) required in the system. Total travel is the sum of all trips; each trip is multiplied by the time required to make the trip. The units are person-minutes of travel.

$$TTRAV = \sum_i \sum_j T_{ij} c_{ij} \tag{6}$$

The third criterion for performance is equity in the provision of access opportunity. In a thought-provoking dissertation, Symons (8) examined in depth the equity concept as it might apply to the service provided by a public facility system. From an examination of court decisions, Symons concluded that a suitable definition for the equity concept is that those for whom opportunity to receive a public service is below some minimum standard are to be considered disadvantaged. He also concluded that efforts to improve equity should be aimed at improving the opportunity available to the disadvantaged portions of the population. The service under consideration here is access opportunity. The accessibility index varies from point to point in geographic space thus allowing construction of a frequency distribution that indicates the fraction of the population receiving a particular level of access opportunity. Then, a deprivation index (DPRVN) can be defined to count up those below some minimum standard of service. Symons suggests for such an index that the difference between the accessibility level of those considered disadvantaged and the minimum standard for accessibility be squared and summed for all those in disadvantaged areas and that this quantity be divided by the total population. The definition is

$$DPRVN = \frac{\sum_i O_i \left[M - \sum_j D_j F(c_{ij}) \right]^2}{\sum_i O_i} \qquad (7)$$

where M = the minimum standard for accessibility $\left[\text{the quantity } \sum_j D_j F(c_{ij})\right]$. The sum over the index i in the numerator is taken only over zones for which $\sum_j D_j F(c_{ij}) < M$.

There is no deductive reason for squaring the difference between an accessibility level of a particular zone and the minimum standard. The choice of the exponential value of 2 is an attempt to weight more heavily those who are significantly below the minimum standard.

Incremental Maximization of Performance Measures

The third part of the methodology is the development of a technique for assigning an increment of growth to a zone so that a performance measure is enhanced to the maximum extent possible. The problem is cast in a combinatorial form. That is, the next person or job could be added to any zone of the region, and the problem is to select the best zone for addition. To obtain a measurable change in the performance measure, people and jobs are aggregated into "chunks" that are allocated at once to a single zone. A population increment of 10,000 people was found to produce a small but measurable change in system performance, and in the case study this chunk could be located in any of 74 zones. Location of the employment increment simultaneously gives 74^2 or 5,476 possibilities. The forecast population growth for a 20-year period is 540,000, which means that the growth could be assigned to zones in 54 allocation steps, yielding a total of 74^{108} or about 10^{200} possible growth sequences.

A growth path through the combinatorial space from the 1970 situation to a future high-performance spatial pattern is determined as follows. A single performance measure, the value of which is to be maximized or minimized through the allocation of population and employment growth, is selected. Because growth naturally occurs more or less continuously in time, each increment can be considered to be the growth that would occur during some small time interval such as a few months. Before each allocation step, the gradient for the performance measure is calculated for all subareas for both population and employment increments. The maximum (or minimum) gradient value is selected, and the growth increment is added to the existing population (or employment) at the zone corresponding to the extreme gradient value. Thus a new point in the combinatorial space is defined, and the system can be considered to have evolved in time for the period during which the growth increment occurred. New gradient values are then calculated, the next growth increments are allocated, and so forth. This allocation procedure simulates the growth of the system in time, and allocation to geographically defined zones results in the evolution of a new spatial pattern of population and employment for the region.

Consider first the task of maximizing increases in TWACC when population or employment increments are added. The differential change in TWACC when an increment in trip origins is added to some zone i′ is

$$\frac{\Delta(\text{TWACC})}{\Delta O_{i'}} = \sum_j D_j F(c_{i'j}) \tag{8}$$

The differential change when an increment is made in trip destinations at a zone j′ is

$$\frac{\Delta(\text{TWACC})}{\Delta D_{j'}} = \sum_i O_i F(c_{ij'}) \tag{9}$$

These quantities are calculated for all zones of the system. The zone for which the quantity in equation 8 is maximum is selected for addition of the next chunk of population, and the zone for which the quantity in equation 9 is maximum is selected for assignment of employment growth.

The objective corresponding to the TTRAV performance measure is to reduce travel requirements, which means that we want to choose zones for addition of growth increments where the differential changes in TTRAV are minimum. The actual differential change values are not readily calculable because the T_{ij} term appearing in equation 6 is written in terms of A_i and B_j (equation 1), which are found by an iterative procedure. However, that the differential change values are nearly proportional to the balancing factors has been found empirically; that is,

$$\frac{\Delta(\text{TTRAV})}{\Delta O_{i'}} \propto A_{i'} \tag{10}$$

and

$$\frac{\Delta(\text{TTRAV})}{\Delta D_{j'}} \propto B_{j'} \tag{11}$$

Therefore, the balancing factors can be used as surrogates for the differential values.

The third objective is to minimize the DPRVN. Because DPRVN has been defined as a property of the accessibility distribution and because the accessibility index is in terms of accessibility to employment opportunities (trip destinations), the location of the population has little effect on the DPRVN unless a population increment were to be located in a subarea where accessibility is already below the minimum standard. The mathematical expressions for the differential changes when population growth occurs are

$$\frac{\Delta(\text{DPRVN})}{\Delta O_{i'}} = \frac{\left[M - \sum_j D_j F(c_{i'j})\right]^2 - \text{DPRVN}}{\sum_i O_i} \tag{12}$$

wherever $\sum_j D_j F(c_{i'j}) < M$, and

$$\frac{\Delta(\text{DPRVN})}{\Delta O_{i'}} = -\frac{\text{DPRVN}}{\sum_i O_i} \tag{13}$$

wherever $\sum_j D_j F(c_{i'j}) \geq M$. The significant changes in DPRVN are made through the addition of new employment. This differential change value is

$$\frac{\Delta(\text{DPRVN})}{\Delta D_{j'}} = \frac{2}{\sum_i O_i} \sum_i O_{i'} F(c_{i'j'}) \left[M - \sum_j D_j F(c_{i'j'})\right] \tag{14}$$

where the sum is over values of i′ for which $\sum_j D_j F(c_{i'j}) < M$. Thus, to provide maximum decrease (or minimum increase) in DPRVN, an increment of population can be located in any place where the accessibility is already above the minimum standard; the increment of employment should be located at the zone where the expression in equation 14 reaches its minimum value.

CASE STUDY

A test of the methodology for developing a growth strategy was designed for the urbanized portion of the Puget Sound region in western Washington. Planning analysis zones used by the Puget Sound Governmental Conference (PSGC), the regional planning agency, were aggregated into 74 zones for the current study, and a transportation network was developed based on the regional highway system. The network is shown in Figure 1. PSGC developed population and employment forecasts for 1990 (9). The forecasting assumptions were that growth would continue according to recent trends, which means essentially a continuation of population growth in the suburbs and employment growth in existing centers, particularly in the Seattle central business district. Population in the study area is expected to grow from 1,670,000 in 1970 to 2,206,000 in 1990, an increase of 32 percent. Employment is expected to increase from 593,000 to 764,000, an increase of 29 percent. The PSGC 1970 and 1990 distributions of population and employment by analysis zone were used as data input for the gravity model; values for the TWACC, TTRAV, and DPRVN performance measures were calculated. These 1970-1990 pairs of values served as benchmarks, indicating the kind of performance to be expected if the urban region continues to grow according to past trends.

Three experiments were performed. In each case, the 1970 distribution of population and employment provided the starting configuration, and a population increase of 500,000 and an employment increase of 160,000 were assigned to zones in increments of 10,000 and 3,195 respectively. In each experiment the objective was to maximally improve 1 of the performance measures as indicated by the following:

Experiment	Objective
1	Maximize increases in TWACC
2	Minimize increases (or maximize decreases) in TTRAV
3	Maximize decreases in DPRVN

If the region is assumed to grow at a constant rate over the 20-year period, then the step size chosen corresponds to a time interval of about 4.5 months. The essence of

Figure 1. Seattle-Tacoma-Everett urban region highway network.

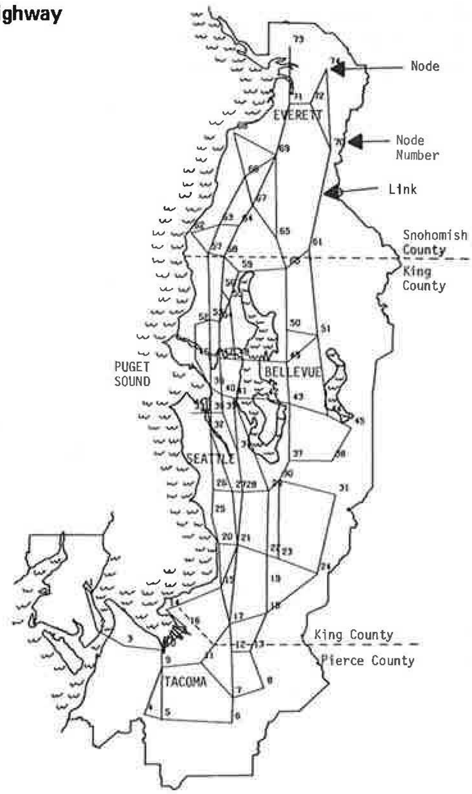


Figure 2. Total weighted accessibility performance during the course of the 3 experiments and for the Puget Sound Governmental Conference 1990 forecast.

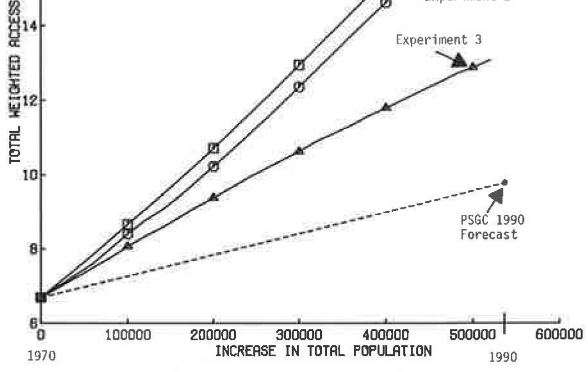


Figure 3. Total travel performance during the course of the 3 experiments and for the Puget Sound Governmental Conference 1990 forecast.

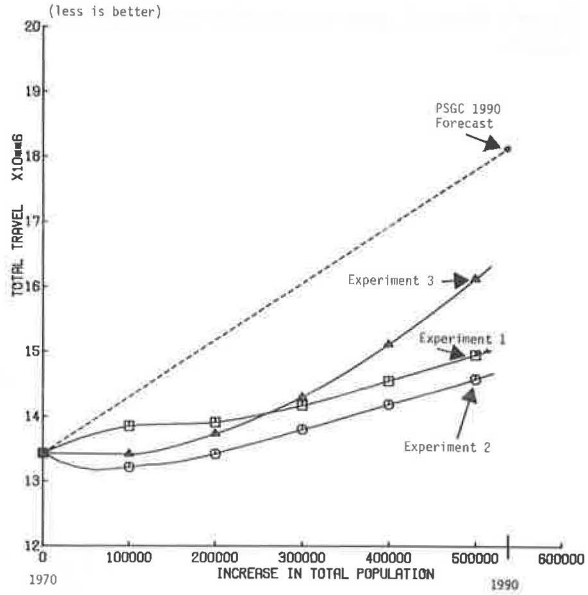
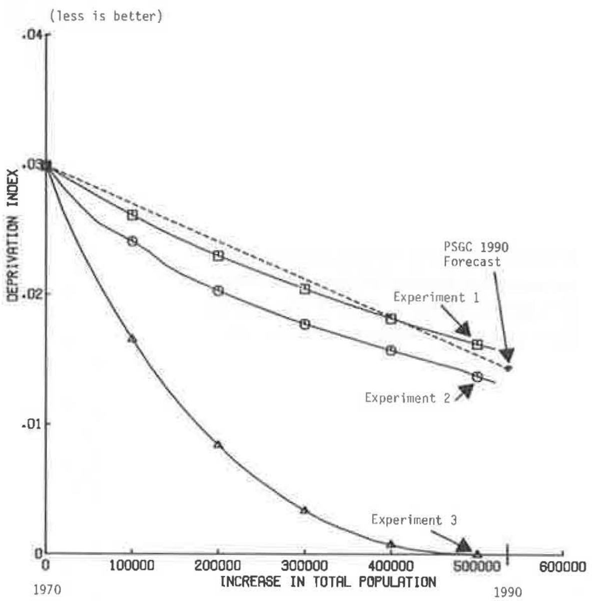


Figure 4. Equity performance during the course of the 3 experiments and for the Puget Sound Governmental Conference 1990 forecast.



the experiment, then, was to assign all new growth for each 4.5-month period to a single location so that a higher performance urban form resulted. Values for all 3 performance measures were obtained in all 3 runs for comparison purposes.

Figures 2, 3, and 4 trace the values for TWACC, TTRAV, and DPRVN respectively at each step for all 3 runs. Values for the 1970 configuration and the 1990 configuration forecast by PSGC also are indicated. These latter 2 values are connected by a dashed line in each figure to indicate how the performance measure might change if the total growth forecast by PSGC occurred continuously and proportionately during the 20-year period. Note that the best performance for each measure was obtained from the run designed specifically to optimize performance for the particular measure. Moreover, in each experiment the final values of all performance measures are generally superior to those of the PSGC forecast configuration. The 1 exception can be seen in Figure 4 where the PSGC 1990 DPRVN measure is better than the value reached in experiment 1. The percentage changes in all performance measures over the 1970 values after allocation of a population increase of 500,000 are as follows:

Item	TWACC	TTRAV	DPRVN
PSGC 1990 forecast	+46	+35	-52
Experiment 1	+164	+11.3	-48
Experiment 2	+152	+8.6	-54
Experiment 3	+96	+20	-100

These results suggest that large improvements in performance can be made through proper guidance of future growth. Substantially increased travel requirements with relatively little increase in accessibility or improvement in the distribution of access opportunity are likely to result if growth continues according to past trends.

The spatial patterns of the growth allocations of the experiments are shown in Figures 5, 6, 7, and 8. Figure 5 shows the locations of the 1970-1990 population growth obtained in all 3 experiments. Figures 6, 7, and 8 show the locations of employment growth in experiments 1, 2, and 3 respectively. The hexagons indicate nodes to which growth was allocated, and the size of the hexagon is proportional to the total quantity of growth. The constraints imposed in the experiments were that a maximum of 100,000 inhabitants and 50,000 jobs could be located at any node. During the allocation process, it was observed generally that 1 particular node remained as the best choice for the next increment of growth. When population or employment at this node reached its maximum allowed value, growth was assigned to the next best node. The overall pattern that emerged after allocation of the total quantity of growth was the highly centralized concentration visible in Figures 5, 6, and 7. Two factors contributed to this result. First, downtown Seattle is already (in 1970) the major regional employment center; therefore, maximum increases in total regional accessibility can be obtained by locating new population close to the existing employment. Second, this location enjoys a highly central location in the network, and, because the city of Seattle also contains the greatest share of the regional population, maximum accessibility continues to result when new employment is located there. Continued allocation of new population and employment to the same, relatively small portion of the network then provides a self-multiplying effect that results in the rapid increase in the TWACC performance measure evident in Figure 2.

Comparison of Figures 6 and 7 shows the highly similar pattern of employment growth that occurred in experiments 1 and 2. The major difference is in the employment allocated to central Tacoma in experiment 2. This portion of the employment allocation occurred at the beginning of the experiment when there was evidently sufficient excess population in the lower portion of the network to cause minimum increases in TTRAV when new employment located there. After about 7 steps of the allocation process, this imbalance apparently was corrected. After that, because new population had been going to Seattle, minimum increases in total travel were obtained by locating new employment close to the developing population concentration. The overall spatial patterns of experiments 1 and 2 are similar and account for the similarities in the temporal changes in all performance measures from these 2 experiments.

The employment growth pattern from experiment 3, shown in Figure 8, is quite different from the first 2 growth patterns. The initial (1970) high value of the DPRVN was due to the people living near the fringes of the network where accessibility is very low. Thus maximum decreases in DPRVN resulted from locating new employment in these areas. Because location of new population has little effect on the value of DPRVN, population growth was located so that TWACC was most enhanced, and this accounts for the population growth pattern duplicating that of the first 2 experiments. Location of this new growth in this manner (population in the center, employment on the fringes)

Figure 5. Locations of 1970-1990 population growth in experiments 1 to 3.

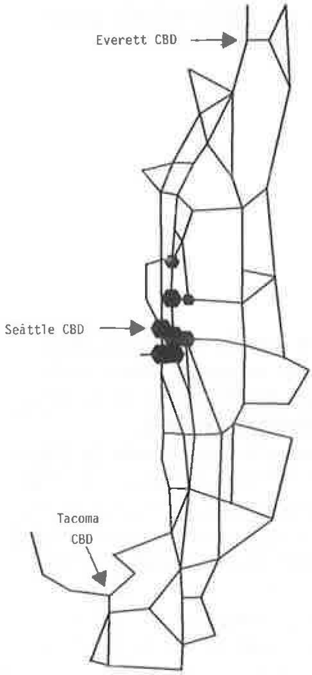


Figure 6. Locations of 1970-1990 employment growth in experiment 1.

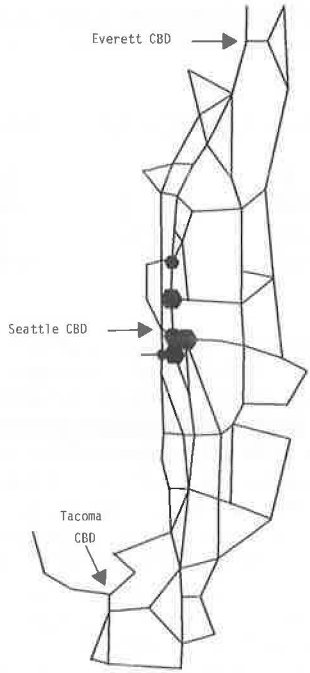


Figure 7. Locations of 1970-1990 employment growth in experiment 2.

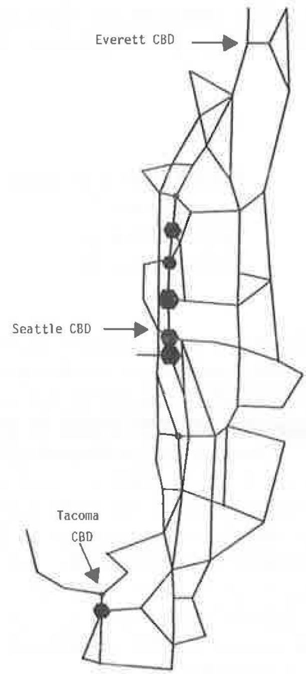


Figure 8. Locations of 1970-1990 employment growth in experiment 3.

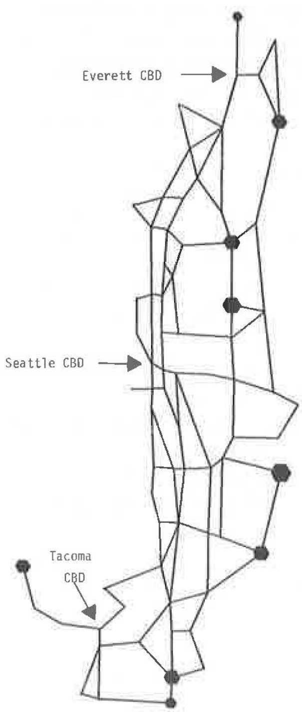


Figure 9. Locations of 1970-1990 population growth as forecast by Puget Sound Governmental Conference.

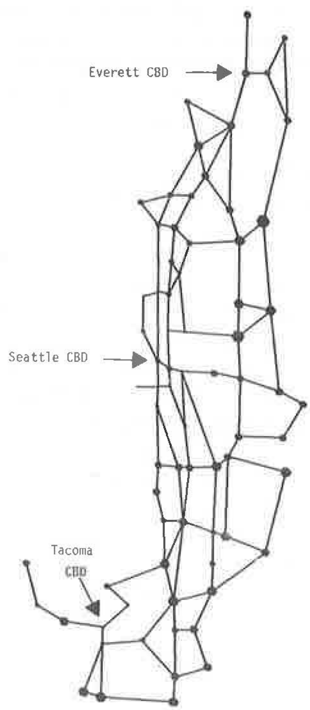
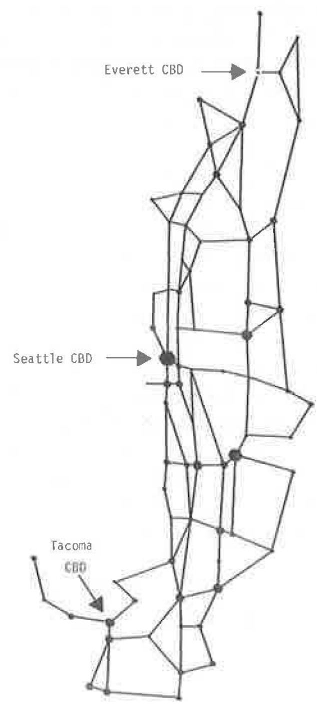


Figure 10. Locations of 1970-1990 employment growth as forecast by Puget Sound Governmental Conference.



begins to have the effect of reversing the 1970 situation (the travel pattern is characterized by much commuting out of the city in the morning), and a low-accessibility, high-travel situation again begins to emerge. In Figures 2, 3, and 4 it is apparent that experiment 3 did not result in TTRAV and TWACC measures as high as are possible. One possibility for trading a little DPRVN to get higher TWACC and TTRAV that is suggested by this experiment would be to locate new employment not quite so close to the fringes, perhaps concentrating it in major centers. Then new population could be located in the center of the region, to make up the "population deficit" currently existing in the city center. It also could be located close to the new employment (perhaps later in the course of the growth simulation) to prevent the renewed buildup of long trip lengths.

For comparison purposes, the spatial pattern of the 1970-1990 growth forecast by PSGC is shown in Figures 9 and 10. Note in Figure 9 the relative absence of population growth in the city of Seattle and in Figure 10 the concentration of employment growth there.

CONCLUSIONS

The use of gradients of performance measures to determine locations where increases in inhabitants or employment will do the most good in terms of improving the performance measure is a useful way to develop 1 kind of urban growth strategy. Repeated use of the technique to allocate small quantities of growth results in a gradually changing urban form with higher accessibility, lower total travel requirements, and a more equitable distribution of access opportunity than would be the case if growth continued according to trends. The technique is simple to implement on a computer, and it appears to be effective in choosing high-performance alternatives from among a large number of possibilities.

In particular, results of the case study suggest that the possibility exists for obtaining sizable improvements in the performance criteria selected if growth for the next 20 years in the Puget Sound region is consciously redirected so that a different urban form emerges than the one that is now occurring. That the case study shows population growth should occur within the city of Seattle is especially significant. Trend forecasts suggest that the city center has stopped growing, and performance of the urban form predicted by the forecasts is substantially lower in terms of all criteria examined. Location of new employment is not so clear-cut. On the one hand, if employment continues to increase in the city of Seattle as has been forecast, then population also should increase significantly in the city center to reduce travel requirements and maintain high accessibility levels without constructing massive new regional transportation systems. The serious question that must then be addressed is whether the resulting, high-density city is desirable on other, non-transportation-related grounds. On the other hand, if new employment could be redirected away from the regional center, then overall low densities apparently could still be maintained along with satisfaction of transportation goals. This latter conclusion must be regarded as tentative until further tests of some alternative urban forms can be made.

Two suggestions are offered for improving the realism of the model used here to obtain results that offer a better basis for policymaking. The first is to include economic implications of alternative urban forms. The use in this study of the equity criterion results in designating as disadvantaged those who live on the fringes of the urban region because accessibility to employment is naturally low in these areas. However, the classical model for land rent and transportation proposes that losses in accessibility incurred by moving far from the urban center are offset by reductions in land rent. If land rents were built into the model, such as might be done through use of a Lowry-type model, then housing and accessibility would be the basic economic goods, and a very different pattern of spatial opportunity and equity might result.

A second refinement would be to abandon the unimodal assumption. The pattern of high accessibility levels in the city center that appeared in the current study may not be so predominant if an account is taken of automobile ownership of city center residents, locations of employment opportunities for this segment of the population, and ease of reaching this employment by public transportation. Wickstrom (10) has suggested such a framework for evaluating the accessibility levels of the highway and transit modes. His framework could easily be fitted into the structure of this study to determine spatial arrangements that make better use of the transit system.

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