Parking Restrictions in Employment Centers: Implications for Public Transport and Land Use

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Measures designed to discourage automobile use and encourage use of alternative modes need to be carefully evaluated to avoid unintended consequences. The impact of a particular set of protransit parking policies on mode and destination choice was examined. A travel demand model with an integrated spatial allocation land use module was used to expand the analysis beyond the narrow question of how mode choice changes within the zones that are subject to the transit-friendly parking policies. Parking supply and/or travel costs to zones with parking restrictions can be adjusted in the model to reflect the restrictions. Discouragement of car travel to some locations influences not only mode choice but can, over time, lead to changes in destination choice and land use patterns that can be detrimental to public transportation. The extent to which such land use changes will take place will depend, in large part, on the nature and implementation of existing land use policy. The desired reduction in automobile traffic is possible only if appropriate parking and business location policies are coordinated and enforced. A stringent parking policy without consideration of long-term impacts on land use development is likely to have little impact on networkwide automobile use but may cause a substantial decline in public transportation ridership.

Advocates of public transportation cite, among other factors, the abundant supply and underpricing of automobile parking as explanations for transit's inability to attract more riders. Free parking is provided by many central-city employers, in what amounts to a tax-exempt benefit to workers who commute by automobile. In the United States, the value of this benefit often exceeds the $60-per-month tax-exempt limit on employer subsidies to workers who use public transit. Many downtown merchants validate customers' parking receipts, making the use of the commonly preferred mode (automobile) even more desirable and transit correspondingly less attractive.

In Europe, despite traditions of high (relative to the United States) levels of transit use, automobile use is on the rise and parking restrictions are being instituted in the old city centers. These restrictions take the form of new or increased parking charges and/or a limitation on the supply of parking spaces. Do such parking strategies tend to equalize the relative perceived costs of auto and transit use, to the relative benefit of transit? Or, does the introduction of new restrictions on auto use initiate (or accelerate) a more general phenomenon: the reallocation of urban activity away from the city center or other urban concentrations of trip ends? If this reallocation is a likely result, the impact of parking restrictions on mode choice should be reexamined in this broader context.

A spatial allocation model developed at Delft University (*1–3*) offers a tool for evaluating the impacts of transportation policy on land use. The spatial allocation model is part of a dynamic multimodal transportation model that describes the interaction between the transport system and land use. The service levels of the public transport and road systems, as well as demographic and economic variables for a region, are used to estimate developments in the location of employment and residences. The spatial allocation model can be used to investigate the impacts on land use of various levels of automobile parking restrictions. More importantly, it can be used to evaluate parking management strategies to determine how well they improve the ability of public transport to serve basic urban mobility needs as part of an integrated transportation system in a region. This paper demonstrates how such an evaluation can be carried out and what results can emerge.

DUTCH LOCATION POLICY

In the Netherlands, a national "ABC" location policy has been established by the Ministries of Land Use and Transportation in an attempt to influence the use of automobiles. The policy attempts to control the location of new employment, subject to the quality of public transportation service. Businesses and facilities that tend to attract large concentrations of work trips are supposed to locate at places that are well served by public transportation or can be easily reached by bicycle. Such a policy seeks to cause positive impacts on economic efficiency and the environment. Businesses with less intensive personal transportation requirements, but with a need for efficient goods movement, are to be located with good access to the road network. Because the shift from unnecessary auto use to public transit and bicycle use is not likely to occur where there is an adequate number of automobile parking spaces, parking policy has become an important part of Dutch location policy (*4*).

The most important part of the parking policy is the reduction in long-term parking places for home-to-work trips in certain locations. The locations are defined in terms of their accessibility to public transportation:

- A locations are very well served by high-quality public transportation.
- B locations are in the vicinity of good public transportation and are accessible by automobile.
- C locations are easily reached by car but are not well served by public transportation.

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Stronger parking standards are being instituted for new developments in A and B locations. These vary, depending on whether the proposed development would be inside the Randstad (the coastal area of the Netherlands that includes Amsterdam, The Hague, and Rotterdam) or elsewhere. Beginning in 1995, national government targets for the number of parking spaces per 100 employees are

- A locations in the Randstad and other designated urban districts, 10;
- A locations elsewhere, 20;
- B locations in the Randstad and other designated urban districts, 20; and
- B locations elsewhere, 40.

These standards apply to locations or zones as a whole, and not to individual businesses. Formerly, the parking policy was applied only to public parking spaces. As a result, businesses often provided numerous parking spaces on their own property, effectively nullifying the parking policy in that area. For example, studies in the Dutch cities of Hengelo and Enschede (*5*) showed that about 75 percent of the commuters parked on company property. Zoning regulations to cover the supply of parking on private property are being formulated in support of the 1995 parking policy.

The establishment of businesses in A and B locations will depend on how these regulations are interpreted and enforced. The policy is implemented by prohibiting the establishment of specified businesses outside of A and B locations. Although the ABC policy is formulated by the national government, the actual policy is carried out by lower-level jurisdictions, such as cities or transportation authorities, which may use stricter or looser interpretations. This study will assume a uniform application of the ABC location policy within a region and confine itself to examining the changes that follow from certain specified parking policies. Toward this end, use is made of a research module in the transportation and land-use software TFTP, to which parking constraints have been introduced.

NETWORKS

A hypothetical but realistic urban area that exemplifies the land-use and public transportation policy issues described herein is shown in Figure 1. The public transportation network consists of heavy rail lines [thick lines in Figure 1 (*left*)] and bus lines [thin lines in Figure 1 (*right*)]. Links without public transport service are not indicated. Parking constraints are applied in zones that are served by rail lines. [These zones are marked with an enlarged shaded circle in Figure 1 (*right*)].

PARKING CONSTRAINTS IN TFTP

The Model With Elastic Constraints

The software package TFTP (*6*) was originally developed for educational purposes to demonstrate the functions of commercial network-based travel demand modeling software. It has evolved into a research tool as well, incorporating components such as the spatial allocation land use model (*3*) used in this study. Figure 2 gives an overview of the revised TFTP software structure. Inputs to TFTP are the road network, the public transportation network, and the current dispersion pattern of residences and workplaces. In the road and public transportation networks, origin-destination (O-D) travel times are calculated. The origin and destination totals are based on current land use patterns. With these trip end and travel time data, O-D matrices for each mode can be calculated. This information is used to determine traffic flows in the auto network and passenger flows in the public transportation network.

The model used in this study calculates distribution and mode choice simultaneously and uses feedback from land use. The model's elastic constraints (*7*) allow for endogenous modification of trip end totals, which reflect a change in land use patterns in response to accessibility. Feedback from car flows to car time to take into account the influence of delay from congestion (*3*) hasn't been applied this time. Also the feedback from public transit (PT) flows to the PT network, the public transit optimization model (*7*), hasn't been used in the analysis that follows. However, for this study, a parking supply constraint has been added to the TFTP model.

TFTP has already been applied to a variety of study areas. It has provided a good representation of existing and forecasted flows and land use patterns in locations such as Washington, D.C. (*3*) and the San Francisco Bay Area (*8*). It is, therefore, reasonable to use the

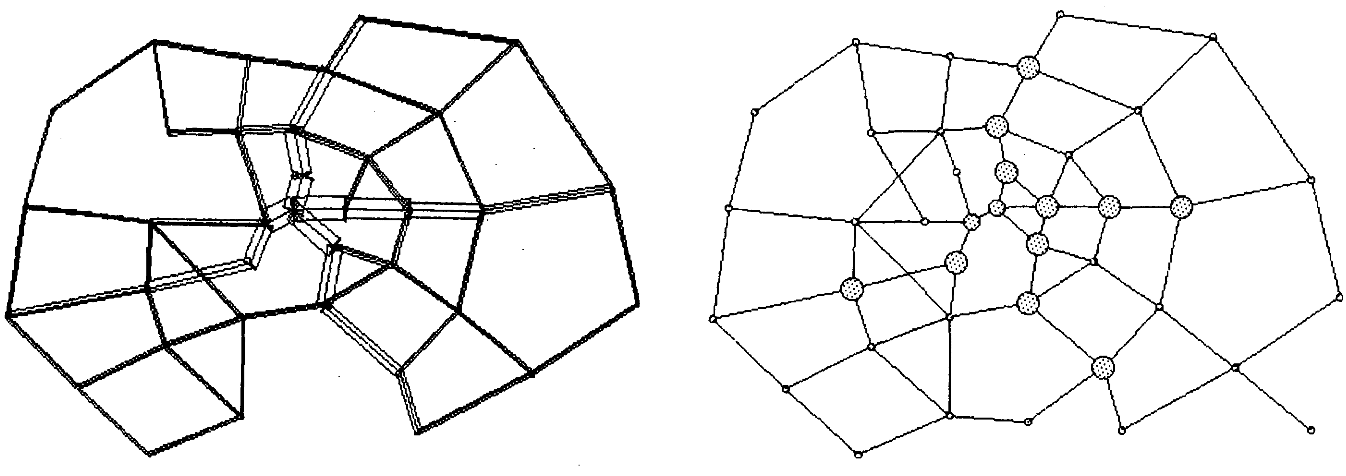

FIGURE 1 Traffic flows in the public transport network (*left*). Zones with parking constraints (*right*).

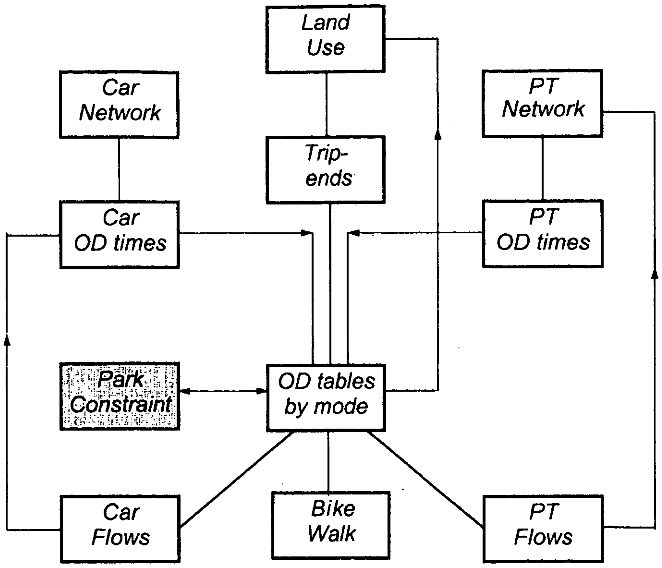

FIGURE 2 Software structure of the transportation and land use model TFTP.

model to analyze the problem being discussed after the parking restrictions are added.

Growth Vector for Distribution, Mode Choice, and Land Use

From the existing spatial distribution the growth vector changes are determined (Figure 3). An earlier paper describes in more detail how trip distribution and mode choice are calculated in conjunction with spatial development (*3*). The number of future jobs in zone i ($\Sigma_j T^f_{ij}$) is the weighted sum of the number of jobs in the base year ($\Sigma_j T^b_{ij}$) and the growth vector ($\Sigma_j T_{ij}$)

$$\left(\sum_j T^f_{ij}\right) = (1-\alpha)\left(\sum_j T^b_{ij}\right) + (\beta+\alpha)\left(\sum_j T_{ij}\right) \tag{1}$$

and the number of workers in zone j is

$$\left(\sum_i T^f_{ij}\right) = (1-\alpha)\left(\sum_i T^b_{ij}\right) + (\beta+\alpha)\left(\sum_i T_{ij}\right) \tag{2}$$

where

α = the replacement rate for real estate in the period between the base and future years, and
β = the growth in the number of workers between the base and future years.

Although the analysis can be carried out for any reasonable time period, this study used p.m. peak-period data. The growth vector is formulated as

$$T_{ij} = \rho l_i E_i m_j W_j F_{ij} \tag{3}$$

$$\sum_j T_{ij} = l_i^{-g} E_i \qquad \forall i \tag{4}$$

$$\sum_i T_{ij} = m_j^{-h} W_i \qquad \forall j \tag{5}$$

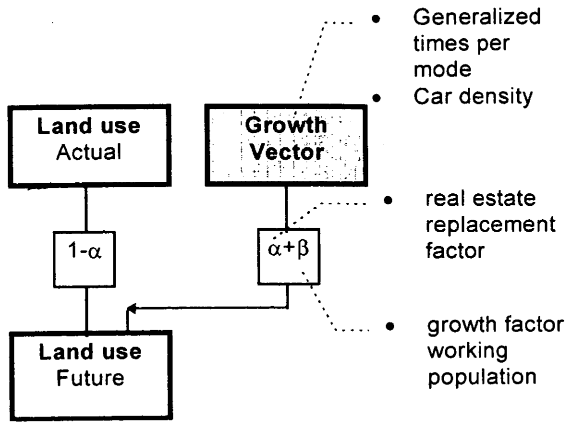

FIGURE 3 Growth vector in the dynamic land use and transportation model.

$$F_{ij} = \psi \sum_m F^{CA}_{ijm} + (1-\psi) \sum_m F^{NCA}_{ijm} \tag{6}$$

where

T_{ij} = the number of trips from zone i to zone j;
F_{ij} = the deterrence function value for trips from i to j;
E_i, W_j = employment in i (the work end) and workers in j (the home end), if the influence of the transport system is neglected;
l_i, m_j = balancing factors for origin zone i and destination zone j;
ρ, g, h = coefficients;
F^{CA}_{ijm}, F^{NCA}_{ijm} = deterrence functions for trip from i to j and mode m for persons with car available (*CA*) or no car available (*NCA*); and
ψ = cars per adult.

The deterrence function for auto trips in the car-available group is the lognormal function

$$F^{CA}_{ija} = e^{-\alpha[\log(c_{ija}+1)]^2} \tag{7}$$

where

F^{CA}_{ija} = deterrence function from i to j for auto drivers (a) among those persons who have a car available; and
c_{ija} = generalized time or cost for trips by auto.

For other modes and for the NCA group, the formulas are similar.

The mode choice has been calculated in the absence of any parking supply restrictions. The results of the "no parking restrictions" case are expressed in numbers of trip ends in the network. They are compared in Figure 4 with the Dutch National Travel Survey (OVG) data. Fifty-five percent of the trips are made by car; walkers and cyclists together account for about 40 percent of the total trips. The mode share of public transit is about 5 percent.

The Parking Constraint

There are two spatial scenarios to consider.

- Scenario 1. The spatial distribution of land use cannot change under the influence of the ABC parking policy. Fixed constraints can be used in the model.

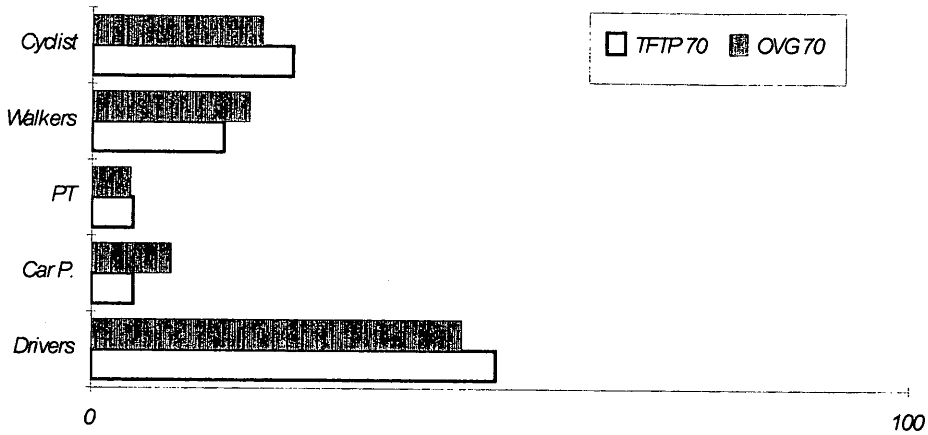

FIGURE 4 Mode choice calculated with TFTP compared with data from the Dutch national traffic survey at the 0.7 car/adult level.

- Scenario 2. The spatial distribution can change under the influence of the ABC parking policy. Elastic constraints must be introduced into the model.

The number of autos in any zone i is calculated using

$$\sum_j T_{ija} = \sum_j \rho I_i E_i m_j W_j F_{ija} = T_{i*a} \quad (8)$$

In A and B zones under the ABC parking policy restrictions, a parking supply constraint (P_i) must be added. As demand for parking places (T_{i*a}) in a particular zone becomes larger than the available number of places ($T_{i*a} > P_i$), a correction is needed so that $T_{i*a} = P_i$. For any zone subject to this parking supply constraint, its deterrence function is modified (using a parameter $0 < \eta_i \leq 1$) to reflect the added "cost" of having limited parking. For example, the deterrence function for auto trips in the car-available group is

$$F_{ija}^{CA} = \eta_i e^{-\alpha[\log(c_{ija}+1)]^2} \quad (9)$$

The subsequent increase in the generalized cost of car travel to zones with parking restrictions has a natural influence on mode choice, destination choice, and spatial development. While the first two (short-term traveler responses) have been studied before, the extent to which spatial development (longer-term developer decisions) is influenced by a particular location or parking policy has received little attention. In this paper, parking restrictions consist of a limit on spaces available. Higher parking charges, or a combination of limited supply and higher charges, could be incorporated into TFTP's generalized cost formulation.

Zone j's parking supply constraint is the zone's employment total ($\Sigma_j T_{ij}$) multiplied by 0.1 (in A locations) or 0.2 (in B locations), with overflow to adjacent residential zones ($\Sigma_j T_{ji}$), if such an overflow is permitted. There are two cases to be considered:

$$P_i = \mu \sum_j T_{ij} + \nu \sum_j T_{ji} \quad (10)$$

where $\mu = 0.1$ in A locations and $\mu = 0.2$ in B locations.

Whether the parking policy succeeds depends on the effects of any parking overflow.

- Assumption 1. A large overflow of parking demand into adjacent zones exists: $\nu = 0.5$.
- Assumption 2. Just a small overflow is presumed. The calculations for this overflow assumption are carried out in combination with spatial Scenarios 1 and 2: $\nu = 0.08$.

CALCULATIONS FOR SCENARIOS

The calculations of changes in existing spatial distribution were carried out with the growth mode contained in TFTP. The calculations are performed with an auto ownership ratio of 0.7 cars per adult, as is expected in the Netherlands.

$$\text{Radius outer circle} \approx \sqrt{\max\left(\sum_j T_{ij}, \sum_j T_{ji}\right)} \quad (11)$$

$$\text{Radius inner circle} \approx \sqrt{\text{abs}\left(\sum_j T_{ij} - \sum_j T_{ji}\right)} \quad (12)$$

If $\sum_j T_{ij} > \sum_j T_{ji}$, zone i is a working area.

No Parking Restrictions

The expected pattern of land-use development in the absence of any parking supply restrictions is shown in Figure 5. The darker-shaded inner circles indicate areas of predominately residential growth, while the lighter-shaded areas represent growth primarily in employment activity. The size of each outer circle in Figure 5 indicates the relative magnitude of the growth rates of the dominant activity. The size of the inner circle pertains to the less dominant activity's growth. The circles in Figure 5 indicate how existing land use will evolve under current accessibility conditions, in the absence of any other factors. Note that employment growth is greatest in Figure 1b where the A and B locations are shown. The results of the "no parking restrictions" case, expressed in numbers of trip ends in the network, are provided in the "No" column of Table 1. Travel mode choice and trip distribution results agree roughly with predictions for the car available group, based on Dutch National Travel (OVG) data. These values, which form the base case against which any scenario and assumption can be compared, will be placed in the "No" column of each subsequent table in this paper. To simplify these comparisons, the total number of trips made in the network will be held constant (subject to rounding errors).

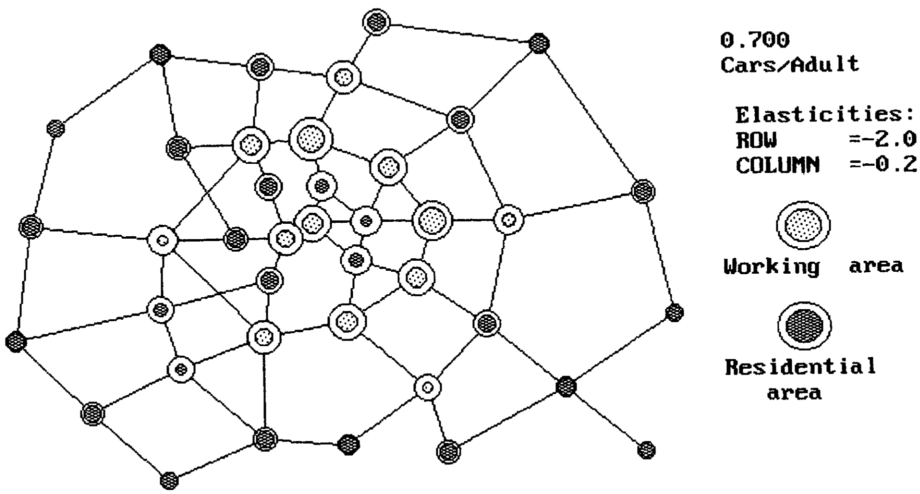

FIGURE 5 Growth vector of land use without parking restrictions.

TABLE 1 Large Overflow to Adjacent Zones

Constraints	No	Fixed	Fixed-No	%	Elastic	Elastic-No	%
Car drivers	240015	239882	-133	100	237686	-2329	99
Car passengers	24477	24463	-14	100	24265	-212	99
PT Passengers	24203	24379	176	101	22610	-1593	93
Walkers	77802	77759	-43	100	80525	2723	103
Cyclist	118635	118799	164	100	120358	1723	101
Interzonal trips	485132	485282	150	100	485444	312	100
Intrazonal trips	73839	73885	46	100	73526	-313	100
Total	558971	559167	196	100	558970	-1	100

Large Overflow to Adjacent Zones

In the first overflow case, it is assumed that a large overflow of parking demand to adjacent zones can occur. If the parking supply restrictions have no influence on the spatial distribution (fixed land use constraints, or the column labeled "Fixed" in Table 1), the changes are less than 1 percent for any mode.

Under the large overflow assumption and the scenario that spatial development does change (elastic constraints), employment shifts away from zones with parking restrictions. By comparing the half-circle of seven employment zones just north, east, and south of the network's center in Figure 5 with the same zones in Figure 6, for example, it can be observed that employment growth is lower in zones with parking restrictions [see also Figure 1 (*bottom*)] and greater in zones without parking restrictions. While networkwide auto use declines (by 2,329 + 212 = 2,541 trips in Table 1), so does public transportation ridership (by 1,593). The parking restrictions eventually lead to (if land use policy allows or can be circumvented) a decentralization of employment centers. In the Netherlands, this would favor greater use of walking (by 2,723 trips) and bicycles (by 1,723 trips) but makes public transit less practical to provide and to use.

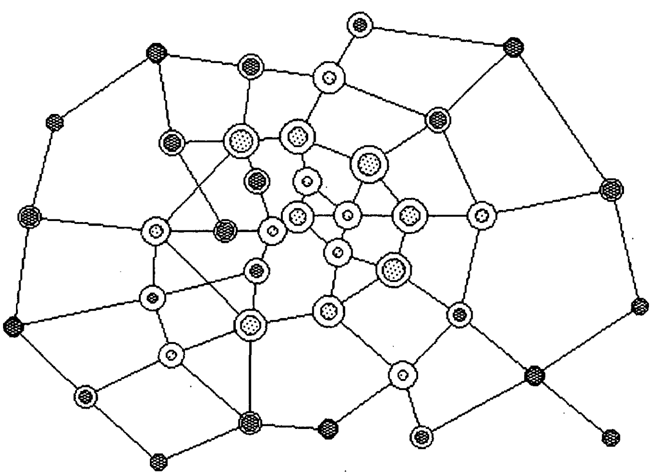

FIGURE 6 Growth vector of land use with a large overflow to adjacent zones.

Small Overflow to Adjacent Zones

In the second overflow assumption, parking policy (and enforcement) allows only a small amount of overflow of parking into adjacent zones. If spatial distribution is not affected by restrictive parking policy (Scenario 1: fixed constraints), then transit, bicycling, and walking take trips away from the automobile (see Table 2.) In other words, strong parking policy and strong land use controls—both strictly enforced—can lead to higher transit ridership.

If spatial development can change (Scenario 2: elastic constraints), trips to workplaces switch from zones with parking restrictions to other zones. If parking "costs" become prohibitive, but businesses can relocate, they will relocate, according to the model. As Figure 7 illustrates, employment growth within the original A and

TABLE 2 Small Overflow to Adjacent Zones

Constraints	No	Fixed	Fixed-No	%	Elastic	Elastic-No	%
Car drivers	240015	221533	-18482	92	235414	-4601	98
Car passengers	24477	22618	-1859	92	24116	-361	99
PT Passengers	24203	29818	5615	123	13810	-10393	57
Walkers	77802	81864	4062	105	87120	9318	112
Cyclist	118635	129880	11245	109	121954	3319	103
Interzonal trips	485132	485713	581	100	482414	-2718	99
Intrazonal trips	73839	72699	-1140	98	76671	2832	104
Total	558971	558412	-559	100	559085	114	100

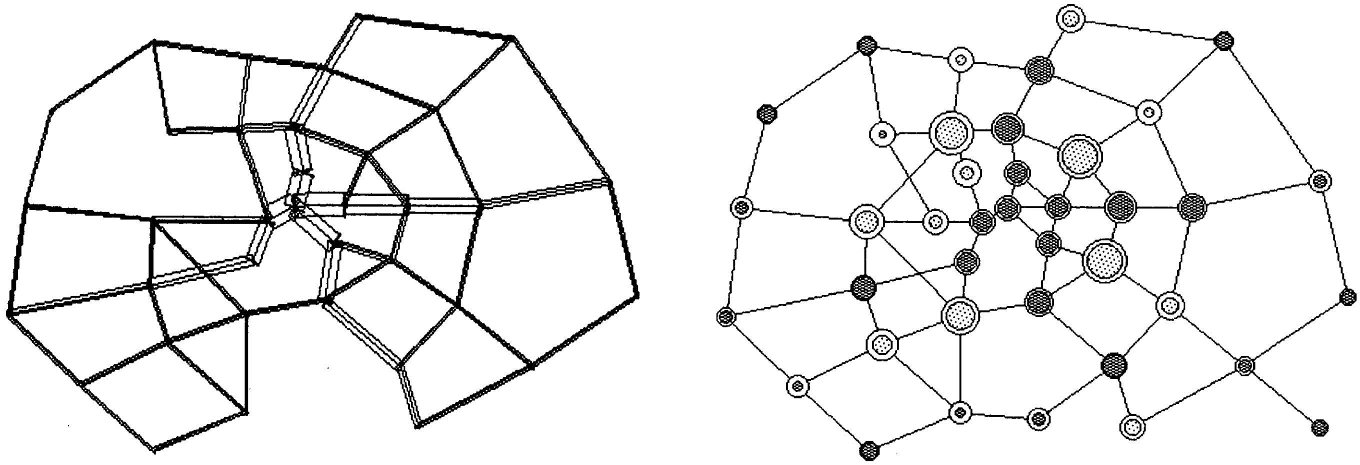

FIGURE 7 Growth vector of land use with a small overflow to adjacent zones.

B zones comes to a virtual standstill but does very well in adjacent zones without such restrictions. The results indicate a loss of almost half the original networkwide transit ridership in favor of walking and bicycling, with auto use affected very little. At the same time, less concentrated land use seems to permit some more intrazonal trips, consistent with a trend to shorter trips that are conducive to walking and cycling modes.

CONCLUSIONS

When calculating the influence of parking policy on travel patterns, attention is usually focused on mode choice. However, factors important enough to influence mode choice may also influence destination choice. If parking policy measures make certain destination choices less desirable, pressures can build to change locations of employment centers.

A stringent parking policy without consideration of its effects on land use development may have little influence on auto use and may lead to a considerable decline in public transit use (Figure 8). The desired reduction in automobile traffic, therefore, always depends on a parking policy coordinated with a location policy.

This philosophy is also valid for shopping and recreational trip purposes. The results of our study demonstrate a tendency for stringent central-city parking restrictions to strengthen pressures to decentralize urban development. If this is allowed to happen, the dispersion of transit demand will have adverse consequences for transit operations. In the Netherlands, where land use controls are traditionally strong, it may be possible to implement a parking policy that will benefit public transportation, but only if the impacts of a proposed set of policies can be anticipated. In the United States, with its looser land use controls and few areas where transit competes well with the automobile, any policy proposals designed to influence mode choice must also be thoroughly evaluated.

Using the spatial allocation model in TFTP permits insights into the relationships between a specific transportation strategy, traveler mode choice, and land use location decisions. These relationships can have important consequences for any area that wants to preserve the viability of existing transit or improve the chances for new transit service responding to changes in land use patterns.

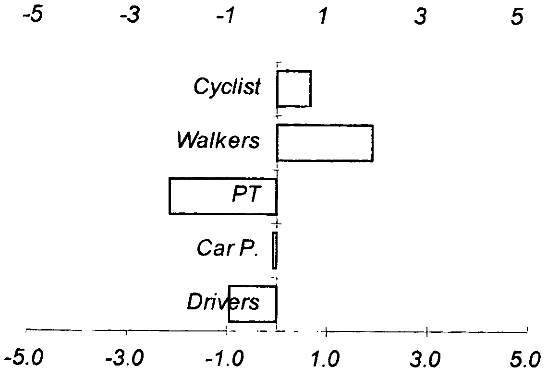

FIGURE 8 Differences in mode choice between a successful ABC policy and "do nothing" policy (*top*). Differences in mode choice with a less effective land use control and "do nothing" policy (*bottom*).

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Publication of this paper sponsored by Committee on Transportation and Land Development.